A
HAND BOOK OF PHYSICS

(For F. A. Students)

BY

AJENDRA NATH CHATTERJEA, M.A.

enior Professor of Physical Science, City College, Calcutta.

Second Edition.
(Improved and enlarged.)

E0408)

Calcutta:
S. C. BASU,
PUBLISHER AND BOOKSELLER,
79/1, Harrison Road.

1895.

Price Rs. 1-4 As.

PREFACE TO THE SECOND EDITION.

An attempt has been made in this edition to afford candidates for the F. A. examination all the information that they need on the subject of physics. Besides many important additions and alterations, the reader will notice many illustrations in the present edition, there being none in the first. The Calcutta University F. A. papers with necessary hints for their answers will, it is hoped, add to the usefulness of the work.

The Publisher.

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A
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PRELIMINARY PART.

1. Physics, physical and chemical phenomena.— The word *Physics* is derived from a Greek word meaning *nature.* Hence *Physical Science* means that department of knowledge which relates to the whole of nature *i. e.* all the natural events. Thus defined it comprises within it, mechanics, astronomy, botany, zoology &c. Nowadays it is applied in a more or less restricted sense, to those branches of science in which the *phenomena* considered are *not only* of the *simplest* and most *abstract kind* but they also *do not produce any permanent change in the body* or *the system.* Thus a distinction may be drawn between a *physical phenomenon* and a *chemical one.* In the former case the *ultimate composition* of *bodies remains unaltered*, and the change consists either in the relative position of different bodies in the system or in that of the different particles of the same body. Change of ice into water, or of water into steam, rise of temperature of bodies, fall and fracture of bodies are examples of this kind. In *chemical phenomena* some permanent change takes place in bodies, the most usual form of which is the change in the ultimate composition of bodies. The burning of wood, the splitting up of water into its two constituent gases, *hydrogen* and *oxygen*, and conversion of iron into rust are examples of this.

2. Province of Physics.—Matter, Mass, Density. Physics has for its domain or field of investigation, the material system, consisting either of a single material particle ; or of a body of definite size made up of a number of such particles, or of any number of such bodies. The first step in physical science is then to define clearly what *matter* is. *Matter* is that which occupies space or whose existence can be perceived by our senses. The *mass of a body* means the quantity of matter contained in the body. The *density* of a body at any temperature really means the *mass* of a *unit volume* of the body at that temperature ; thus the density of water at 4° C. is one gram per cubic centimetre. The *specific gravity* of a body is the *ratio* of the *mass* of the *body* to the mass of an equal volume of the standard substance, generally water at 4° C. under the same physical conditions. Thus it is evident, specific gravity being the ratio of two quantities is altogether independent of units. In many physical text books the terms *density* and *specific gravity* are *used* synonymously, the *former* being generally employed *for gases* and *liquids* and the *latter for solids*.

3. Elements, Compounds.—Matter is divided into two chief classes, *simple* or *elementary* bodies and *compound* bodies. A simple substance is a body which *cannot be split up* into two or more bodies differing altogether from the original one in chemical properties ; as gold, iron, sulphur &c. A *compound* body is that from which can be produced bodies differing in chemical properties from the original one ; as water, wood, marble, salt &c.

4. Atoms, Molecules.—Physicists having observed that matter is not continuous but composed of small particles lying close to one another, assumed that all material bodies are composed of minute indivisible particles, called *atoms* ; that these atoms cannot exist in the free state in nature, but they combine together to form small *groups* called *molecules* ; that molecules of an element are composed of similar atoms. The *atoms* then are *the smallest portions of matter that can take part in chemical reaction only*. Again, the *molecule* or minute particle of a compound, (sugar for instance), which can exist in nature, is still a compound body and still contains in this instance its constituents, carbon, hydrogen, and oxygen. Thus a *molecule* is the *smallest portion* of *matter*, whether element or compound, *that can exist in the free state in nature.*

It is evident that a molecule *cannot* be divided *mechanically* but it may be separated into its constituent atoms by *chemical or physical force.*

5. Molecular forces.—The forces which hold together ultimate particles or molecules of a body are, (1) cohesion, (2) adhesion, (3) chemical affinity. *Cohesion* is the force which unites two molecules of the *same nature.* The existence of a body as a solid in one continuous mass is owing to the exertion of this force. It is strongly exerted in solids, less so in liquids and scarcely at all in gases. It varies with the nature of bodies as well as with the arrangement of their molecules and this variation produces varieties in the toughness, hardness, and brittleness of bodies. *Adhesion* is the force manifested by two bodies when their surfaces are placed in contact. It is applied to those cases of molecular attraction where the bodies are different. *Chemical affinity* is the force which unites the elements into compound bodies. The effects of *chemical attraction* may be distinguished from those of cohesion, by stating that the molecule of a body is formed by the union of atoms under the influence of chemical attraction, whilst the *mass* is formed by the union of molecules under the influence of *cohesion* ; water drops stick to the surface of a glass plate by the force of *adhesion.*

If molecular attraction were the only force acting upon the particles of bodies, they would come into complete contact, which is never the case. Hence molecules are also under the influence of another force which acts in opposition to molecular attraction and keeps the particles in a state of constant motion. This force is *heat.* It has been proved that it is impossible to extract the *whole* of the heat of a body ; hence this *repulsive* force *always* acts on molecules in opposition to molecular forces.

6. Difference between physical and chemical properties.—The properties which characterise objects in general, may be classed under two heads, viz., *physical* and *chemical.* The *physical properties* of an object are those which refer to its condition or state of aggregation (whether solid, liquid, or gaseous) and not to its elementary composition. Crystalline form, specific gravity, hardness, colour, transparency or opacity, and the relations of the object to heat and electricity are also physical properties. The *chemical properties,* of the body on the other hand, refer essentially to its action upon other bodies and to the permanent changes in composition which it either experiences in itself or which it effects upon them.

7. Different physical states of matter.—Matter exists in nature in three distinct forms, viz., solid, liquid and gaseous. The same body may be made to assume any one of these conditions at different times and pass from one to the other for an indefinite number of times, according as it is exposed to a greater or less degree of heat. Ice, water and steam are the same material in three different states.

These changes in the physical condition of bodies prove that molecules of bodies besides being acted on by the force of molecular attraction are also under the influence of other forces, (as heat, electricity &c.) which act in opposition to the former. These latter also keep the molecules in a constant state of rotation, continually tending to separate them from one another.

It is assumed that in the *solid state* molecular attraction prevails over repulsion, and the molecules vibrate about *fixed* centres. In the *liquid state*, molecular attraction is in equilibrium with repulsion (produced by heat, &c.) and the molecules vibrate about centres that are movable also. In the gaseous state repulsion prevails over molecular attraction and consequently molecules continually tend to occupy larger space.

8. General properties of matter.—*Properties* of *bodies* denote the different ways in which they present themselves to our senses, and *general properties* mean those that are common to all bodies in the three different states. They are *extension*, *impenetrability*, *divisibility*, *porosity*, *compressibility*, *elasticity*, *inertia* and *gravity*. *Special properties* are those that are observed only in certain states of bodies; as solidity, fluidity.

Extension or magnitude means the property which every body possesses of occupying a portion of space. When it is considered in *one direction* only, it gives a *line*; in *two directions*, a *surface*; in *three directions*, a *volume*.

Impenetrability.—Is the property in virtue of which two portions of matter cannot simultaneously occupy the same portion of space. Thus when a stone is placed in a vessel of water the volume of the water increases by an amount equal to that of the stone; the *volume* of an *irregularly shaped body* may be *determined* by this method by taking a graduated vessel and measuring the amount of increase. This property applies *only to* the *atoms* of a *body*. For in every body there are intermolecular spaces, and when any two bodies (such as water and alcohol or sulphuric acid) are mixed together, they in some cases seem to penetrate each other *i. e.* the volume of the mixture is less than the sum of the volumes of these two bodies before the mixture. This is explained by the fact that some of the intermolecular spaces of the one body are occupied by the molecules of the other body.

Divisibility.—Is the property which bodies possess of being divided into distinct parts; thus, a single grain of gold may be hammered out so as to cover seven square inches, each square inch may be cut into strips, and each strip into 100 pieces, each of which is distinctly visible. Again when a substance is dissolved in any liquid the subdivision is carried so far as to escape our eyesight even when aided by a powerful microscope. Also a piece of musk diffuses its odour over a large area of atmosphere, thus proving that it is divided into innumerable minute particles. These things tend to prove that matter is capable of *infinite* division, but experience shows that divisibility of matter may be manifested to an extent which indicates further division beyond our conception. Also the *atomic theory* presupposes that divisibility of matter has limit and that the *atomic state* of bodies is the *limit* of that property.

Porosity.—Is the property which bodies possess of having interstices or spaces between their molecules, called *pores*. It follows at once from the atomic theory. It is proved by the property called *compressibility i.e.*, that of being diminished in volume without undergoing a loss of mass. Two kinds of *pores* exist in bodies; (1) *physical* or *intermolecular* pores, where the interstices are so small that molecules appear to remain within the sphere of their mutual attraction. These are not visible but the contraction of bodies under certain circumstances proves that they have such pores. (2) *Sensible* pores are the holes that are observed in certain bodies such as wood, sponge, animal and vegetable tissues. The *porosity of liquids* may be *proved* by taking a long narrow tube with a couple of bulbs blown in it, filling the tube and lower bulb with water and the neck and the upper bulb with spirit. If now the open end be stopped and the liquids mixed together by turning the tube upside down several times, the mixture will be found to occupy less volume than before.

Compressibility.—Is the property of occupying smaller space under greater pressure. The change for unit of volume due to unit increment of pressure is called the measure of compressibility; the reciprocal of compressibility is the *elasticity of volume.* All bodies are more or less compressible; Gases are most so, liquids less and solids the least. This property of a gas may be proved by taking a thick air-tight syringe with its mouth closed; the piston may be driven in by increasing the pressure, so as to make the air occupy smaller *volume.*

Inertia.—*Is* the property of matter in virtue of which it cannot of itself change its own state, either of rest or of motion. It is self-evident that when a body is at rest it remains so until some force acts on it. But the other part seems to be paradoxical, since actual experience shows us that a body set in motion gradually comes to rest. This is accounted for by the fact that the motion originally imparted to the body is impeded by gravity and by the friction of the neighbouring bodies (air, &c) ; for it has been observed that the lesser these resistances are, the more prolonged is the motion. And since one is proportional to the other, it may be inferred that if all impeding causes were removed, a body once in motion would continue to move for ever. A marble ball rolled amongst grass, or a gravel path, a smooth pavement, or on ice, has a proportionate progress ; moving an immense distance on smooth ice compared to what it would on grass, because it has less friction to overcome on the ice than on the grass.

EXAMPLES.—A person jumping from a carriage in motion tumbles down in the direction of the motion of the carriage, for while in the carriage the whole body acquires the velocity of the carriage, but on descending as soon as the feet come in contact with the earth, they are brought to rest, but the upper part retains its motion and consequently he falls. The jerk that is given in a Railway carriage on the commencement of motion or on the sudden stopping of it, may be explained by the inertia of matter. In a circus, the performer standing on the back of a galloping horse, leaps over a garter or through a hoop by simply jumping up ; for having already the motion of the horse, he goes forward at the same rate as when on horse back ; were he to add force to this forward motion, he would leap over the horse's head. Before leaping a ditch we run towards it, in order that the motion of our bodies at the time of leaping may be added to the muscular effort then made. If a card be balanced on the tip of a finger, then a coin placed on the card, and the latter receive a smart tap, it will fly away leaving the coin on the finger-end. In order to shake off the dust from the coat, we only beat it with a stick.

Gravity.—In whatever form matter exists, whether visible, as in the liquid or solid state, or invisible, as in the gaseous state, it is always under the influence of the earth's attraction, called *gravity*, which confers on it the property of weight.

Internal constitution of matter.—Thus we learn that matter is not continuous but is composed of indivisible particles called atoms. These atoms combine together to form little groups called *molecules* that exist in the free state in nature. These molecules are held together by a force of attraction. But porosity or compressibility shows that these molecules are not in absolute contact with one another. If attraction were the only force acting on the molecules they would be in complete contact with one another. Hence we see that molecules are also under the influence of another force which keeps them apart and which therefore acts in direct opposition to the force of attraction. This force of molecular repulsion is called *heat.* It is always present in a body and it has been proved that it is impossible to extract the whole of the heat of a body.

9. Properties Special to Solids—Besides the general properties of matter, there are some *properties* that *are peculiar* to bodies in the *solid state*; they are *tenacity*, *hardness*, *ductility* and *malleability.*

Tenacity is the resistance which bodies offer to being broken or pulled asunder when subjected to a greater or less stretching. It is the force with which the atoms of any body cling together. Every body possesses this property more or less. The tenacity of a body is tested by the weight it will bear. *It varies directly* as the *breaking weight* and inversely as the *sectional area of the body.*

Hardness—is the resistance which bodies offer to being cut, scratched or worn by others. It has no relation to its resistance to compression. It depends upon the manner in which atoms are arranged.

Ductility is the property that many solid bodies have of changing their forms under traction. It is owing to this property that some metals can be drawn into wire.

Malleability is the property by which a thing can be beaten into thin plates without being broken or cracked. It is a modification of ductility, which is exhibited when bodies are hammered. It increases greatly with the temperature.

10. Special properties of liquids—A *fluid* is a substance, such that a mass of it can be very easily divided in any direction, and of which portions however small can be very easily separated from the whole mass. Special properties of a fluid are extreme *mobility* of its *particles* and the *entire absence* of *friction* on the neighbouring bodies, so that the pressure of a fluid at rest on any surface with which it is in contact is *perpendicular* to the surface. A slight tangential force is exerted by fluids in motion and this fact is expressed by saying that fluids are more or less *viscous*. *Fluids* are of two kinds, liquid and gas, the former being *practically incompressible*; it is by this essential property that a liquid is distinguished from a gas, which is compressible. Liquids are however really *compressible*, but to a *very slight* degree. The compressibility of liquids has been proved by an instrument called the *piezometer*. It consists of a capillary tube with a bulb on its end, enclosed in a strong glass vessel, (which also contains a manometer.) The liquid to be examined is first introduced into the bulb and then a drop of mercury to isolate the liquid. The vessel is then filled with water and closed by a movable piston. By means of a screw any required pressure can be produced. The manometer measures the pressure, and the compression of the liquid is determined by observing the space through which the drop of mercury in the capillary tube is forced. Liquids also possess the general properties of matter, such as porosity, impenetrability, &c.

11. Pascal's law—Pressure exerted anywhere upon a mass of liquid is *transmitted undiminished in all directions*, and *acts with the same force on all equal surfaces* and *in a direction at right angles to those surfaces*. This law has been established by assuming liquids as perfectly fluid, incompressible and uninfluenced by the action of gravity. To prove this, take a vessel of any shape having several openings (in different directions,) closed by movable pistons and kept in their positions by suitable forces. It will be found that any additional force applied to one piston will require the application, to all the other pistons, of additional forces, proportional to the areas of the respective pistons, so that on equal surfaces the pressure is the same. This is called the *law of equality of pressure*, thus it follows from this law that *the pressure transmitted* by a *liquid* is proportional to the extent of the *surface*. The whole of the science of hydrostatics is based on the principle of equality of pressure. It has been applied to practice in the *hydraulic press* by means of which enormous pressures may be produced.

12. Hydraulic Press—It consists of two *solid cylinders* or *rods* working in air-tight collars within two strong hollow cylinders connected by a pipe. The rod of the smaller cylinder is moved up and down by a lever. On the top of the rod working in the larger cylinder (whose diameter is n times that of the smaller one,) is a movable platform, on which the substance to be pressed is placed. This plate presses the body against another fixed plate placed above on iron supports. At the bottom of the smaller cylinder, which is connected by means of a pipe with the reservoir of water, is a valve opening upwards into the cylinder; also at the point where the connecting tube enters the larger cylinder, there is another valve opening into the latter. *Action of the press.*—When the smaller rod is raised the atmospheric pressure forces water from the reservoir through the valve at the bottom; when it is forced down, this valve closes but the valve near the bottom of the larger cylinder opens and a portion of water is driven into it and the rod is made to ascend with the platform. A continued repitition will produce the required compression of the body placed on the platform. From the principle of equality of pressure it follows that the amount of downward force applied to the smaller piston is transmitted upward to the larger one and is magnified there in the proportion of the sectional area of the latter to that of the former, (which is n^2 times in this case). This principle is also applied to hydraulic lifts, cranes, hydrostatic bellows, &c.

13. Lateral pressure—The *Hydraulic* tourniquet or *Barker's* mill proves the existence of lateral pressure of liquids on the containing vessel. It consists of a hollow cylinder provided with a funnel at the top and capable of rotating about a vertical axis. It has two or more *horizontal* tubes inserted into it at the lower end, which is closed. These tubes are either all bent in the same direction at the ends or they have lateral apertures all on the same side of the tube. The water is poured down the cylinder through the funnel and a stream of water flows through the bent end or orifice of each tube. The instrument is then seen to *rotate* about the vertical axis in the *direction opposite to that* in which *water flows.* This rotation is due to the lateral pressure exerted by the column of water in the cylinder on the sides of the horizontal tubes. These pressures balance each other at every point except at the openings where there is an uncompensated pressure on the side of each tube opposite the orifice. These forces form couples the effect of which is to cause rotation. By means of a toothed wheel attached to the axis of rotation the instrument may be made to work machines.

14. Upward vertical pressure—when any liquid is at rest any horizontal layer within the liquid is supported by the *upward vertical* pressure of the layer below, which is equal to to the *downward* pressure due to the weight of the layers above. This is a necessary consequence of the law of equality of pressure. If a glass tube open at both ends be taken and a thin plate of any light body (card board, mica, &c.) be placed at the lower end, it will be seen that some force is required to keep the plate in its position. But if the tube with the plate be immersed in water, at a certain depth the disc will be observed to remain in its position without any support. This then proves that it is kept in this place by the upward pressure of the liquid. If now water is poured into the tube, the disc will sink when the downward pressure of water *plus* the weight of the disc is greater than the upward pressure. And neglecting the weight of the disc, it is seen that when the height of water inside the tube is the same as that of water outside, the disc begins to sink. Hence the *upward pressure* at any point is the same as the downward pressure. The upward pressure is called the *buoyancy*.

15. Downward pressure—The *mere weight* of the liquid itself is sufficient to produce pressures, which *vary with* the *depth* and with the *density* of the liquid. If we imagine a liquid to be divided into horizontal layers of equal thickness, it is clear that the second layer supports a pressure equal to the weight of the first; the third layer supports the weight of the first and the second; and so on; so that the pressure increases with the number of layers, which is expressed by saying that *gravity produces in liquids pressures proportional to the depth.* These pressures are also proportional to the densities of liquids. Since, for the same depth a liquid which is denser will exert greater pressure.

16. Hydrostatic Paradox.—Now, this *pressure* exerted by a liquid in virtue of its weight on any portion of the liquid, or on the sides of the containing vessel, though it depends upon the *depth* and *density* of the liquid, is *independent of the shape of the vessel* and of *the quantity of the liquid.* This is called the *hydrostatic paradox.* It follows directly from the law of equality of pressures. It may be proved by an instrument, which consists of a support carrying a ring into which may be screwed vessels of different shapes. Beneath the ring is a moveable disc supported by a string attached to one of the scales of a balance, weights being placed in the other scale to keep the disc pressed against the ring. Let a cylindrical vessel be placed on the ring and filled with water to such a level that the pressure is just sufficient to detach the disc from the ring, an indicator being used to mark the level of water in the vessel. If the experiment be repeated with other vessels of different shapes (conical, spiral, tapering, &c.) the disc will be found to be detached when the water has reached the same level as before. It is evident that in the case of the cylindrical vessel, the pressure on the bottom is equal to the weight of the liquid ; hence, *in every case*, the *pressure* on the bottom of the vessel is *equal* to the *weight* of a *cylindrical column* of the *liquid* having the bottom as its base and having the *same height* as that of the liquid in the vessel.

As it has been shewn just now that the pressure of a liquid depends upon the depth of the liquid and *not* on its quantity, it is evident that *very great pressures* may be *produced by* even *small quantities of a liquid* placed in a very narrow vessel of great height. Pascal proved this by firmly fixing in a strong barrel a very narrow long tube filled with water, the effect of which was to burst the cask. Here the pressure on the bottom is equal to the weight of a column of water whose base is the bottom itself and whose height is equal to that of the water in the tube.

17. The pressure of a liquid at rest is the same at all points in the same horizontal plane.—This appears from considering the equilibrium of a horizontal cylinder of the liquid of small sectional area, its ends being right sections. The pressures on the sides of this cylinder are normal and give no component in the direction of length. Hence the pressures on the ends must be equal in magnitude ; and since they act on equal areas their intensities are equal. A horizontal surface in a liquid at rest may therefore be called a "*surface of equal pressures.*"

18. Free surface. Conditions of Equilibrium.—The *free surface i.e.*, the surface in contact with the atmosphere of a liquid at rest *must be horizontal.* This may be proved indirectly by taking two points within the liquid in the same horizontal plane. The pressures at these two points are equal, and since the pressures depend upon depths only, the depths of these two points must be equal. Similarly it may be proved that all other points on the surface of water are equidistant from the points on the horizontal plane below. Therefore the free surface is horizontal. This is in fact the converse of the foregoing proposition, the pressure on all points of the free surface being the same (= the atmospheric pressure), the points must be on the same horizontal plane. Hence *a liquid at rest must satisfy the following conditions.* 1. The free surface of a liquid must be horizontal *i. e.* perpendicular to the direction of gravity (or plumb-line). 2. Every molecule within the mass of the liquid must be subject to equal pressures in all directions. The first has already been proved and the second is self-evident; since if the pressures on the molecules were not equal, the molecule would be moved in the direction of the greater pressure; but the liquid being at rest the pressures are equal. When other forces than gravity (capillary, &c.) come into play, the free surface of the liquid no longer remains horizontal.

19. Level.—A liquid is said to be apparently level when all the points of its surface lie in the same horizontal plane. This applies to surfaces of small extent. As the direction of the vertical constantly changes from one place to another on the surface of the globe, the direction of the horizontal surfaces changes also. Therefore in the case of a large extent of water the surface is said to be level when all the points in it are equidistant from the surface of the earth. This is called the *true level.* The true level coincides with the apparent level when the surfaces are very small.

20. Condition of Equilibrium in communicating vessels.—When *a liquid* is placed *in vessels* of different shapes and dimensions *communicating with one another*, it *comes to rest* when *the surfaces* of the liquids in all the vessels *are in the same horizontal plane.* This is sometimes expressed by saying that *liquids maintain their level.* This is evident, for the pressure at every point in the communicating tube when it is placed horizontally is the same, and as this pressure depends upon the depth only, all points in the free surfaces of water in different vessels must lie in the same horizontal plane.

If *two liquids of different densities* are poured *into* two *communicating vessels* of different dimensions the condition of equilibrium is that their *heights above this surface of junction* must be *inversely proportional* to *the densities*, for at two points in the same horizontal line in the two tubes the pressures would be equal. But the pressures are $h.\ d$ and $h.'\ d'$ respectively, where h and h' are the depths of the points and d and d' the densities of the liquid.

$$\because \quad hd = h'd' \quad \therefore \quad \frac{h}{h'} = \frac{d'}{d}$$

21. Several liquids in one vessel.—When several liquids which do not mix are superposed one upon another in a phial, each of them must satisfy the conditions of equilibrium necessary for a single liquid and also they are *arranged in the order of* their *decreasing densities from* the *bottom upwards.* Even after the liquids have been well stirred if the phial is allowed to rest they separate and arrange themselves in that order.

22. Artesian wells.—It has been observed that liquids *tend to find their own level.* This *tendency* of liquids is *utilised* for the *water supply of* some *towns.* At first water is raised to a reservoir placed at a great height which then finds its way through all the pipes connected with the reservoir, provided that all parts of them are below the level of the water in the reservoir. Water issues from taps with a force proportional to the difference of level of water here and that in the reservoir. But it never attains the higher level for the jet experiences four kinds of resistance. 1. The friction of the water in the pipe ; 2. The resistance of air ; 3. The attraction of the earth ; 4. The resistance offered by the particles falling from the top of the jet upon those ascending. *Jets of water in gardens* are constructed on this principle and all natural collections of water exemplify this tendency. The formation of *natural springs* on the surface of the earth and in its interior is also due to this tendency of water to seek its level. The rain which falls on the surface of the earth partly penetrates into it, and is collected under the earth. This water issues at a certain force from a place at a lower level. The most striking instance of this class of phenomena is that of *Artesian wells.* These wells derive their name from the province of Artois in France where it has long been customary to dig them and whence their use in other parts of Europe is derived. *Its theory.*—The crust of the earth is made up of two kinds of strata :—permeable, as sand and gravel, and impermeable as clay. Now suppose that a basin is composed of two impermeable layers, enclosing between them a permeable layer. The rain water falling on this layer of sand and gravel will filter through it and collect in the hollow of the basin or will fill the whole of the permeable layer whence it can not escape owing to the layer above and below it. If now a well be dug in the impermeable layer above, as soon as it reaches this stratum water striving to regain its level will issue through the opening with a great force depending on the difference of the level of the point and that of the exposed part of the permeable layer.

23. Water level.—The instrument called water level is an application of the principle of equilibrium in vessels communicating with one another, in which the surfaces of the liquid in the two branches are in the same horizontal plane, so that if the line of the observer's sight just grazes the two surfaces it will be horizontal. It is used in *levelling* or determining the difference of the vertical heights of two places. It consists of a metal tube bent perpendicularly in the same direction at both ends, in which two glass tubes are fitted. The tube is placed on a stand and water poured until it rises in both legs. In levelling a graduated staff with a movable slide is first fixed vertically in one place and the observer looks at it along the level of the surfaces of water in the two tubes. The slide in the staff is lowered or raised until the mark is on the line of the level. The number of graduation on the staff is read off. It is then fixed on a second point and the graduation is similarly read off. The difference between these two gives the difference of the heights of the two places.

24. Spirit Level.—It consists of a glass tube, slightly curved and is filled with alcohol with the exception of a bubble of air which tends to occupy the highest point. It is fitted in a brass case which is so arranged that where it is perfectly horizontal the bubble of air exactly occupies the space between the two points marked in the case. To level anything with the apparatus it is placed on the thing or the instrument and the latter adjusted until the bubble occupies the position indicated above.

25. Archimedes' principle. Hydrostatic balance—When a body *is immersed in a liquid it is pressed upwards by a pressure equal to the weight of the liquid it displaces.* Imagine a cube immersed in water with its four edges vertical, the horizontal pressures in its lateral faces are equal and opposite as they are exerted at equal depths. The downward vertical pressure on the *upper face* is equal to a column of water whose base is the face itself and whose height is the depth of the face from the free surface of water, whereas the upward vertical pressure on the lower face is the weight of a column of water whose base is the face itself and whose height is equal to the former height *plus* the height of the cube. Thus the resultant pressure acting on the cube is an upward force equal to the difference of the two vertical pressures, *i. e.*, equal to the weight of a column of water having the same base and height as the cube. Hence *a body immersed* in a liquid *loses its own weight* (which is due to a downward force called gravity) *by this amount, i.e.*, by the weight of its own volume of the liquid. The above principle is called the *principle of Archimedes.* To prove this by means of the *hydrostatic balance.*—This is an ordinary balance, each pan of which is provided with a hook at the bottom. The beam of the balance being raised, a hollow cylinder is attached to the hook of one of the pans and to this a solid cylinder is attached whose volume is exactly equal to the capacity of the hollow one. Weights are placed in the other pan to keep the balance in equilibrium. If now the beam be lowered so that the solid cylinder is completely immersed in water, equilibrium will be lost, but on filling the hollow one with water it will be restored. This proves that the weight lost by the former on immersion is equal to the weight of the same volume of the liquid. By means of this apparatus the *specific gravity* of the body *may be determined* in the following manner. First weigh the substance in air and suppose the weight to be w, then weigh the same in water and suppose now the weight to be w'. Then $w = wt.$ of the substance in air ; $w - w' = wt$ of the same volume of water (the standard substance) $\therefore$ *sp. gr.* of the body $= \dfrac{w}{w - w'}$

26. The circumstance of any solid body displacing its own bulk of liquid and losing as much of its weight as the weight of the bulk of liquid it displaces has led to the *use of* the *hydrostatic balance* for ascertaining the intrinsic value of gold and other precious metals (and also for determining the quantity of impurities present.) For example, by knowing in the first place, how much water a pound of pure gold displaces, and then weighing in water an object said to be a pound of gold, we should observe whether it displaces the proper quantity of water. If it displaces more than was proper then we should be certain that it contains an alloy or some inferior body, being too bulky for a pound of gold. Such a mode is sometimes adopted by goldsmiths. To determine the quantity of different bodies present in the alloy

Let $x = wt$ of gold present
$y = \ldots$,, silver...,,
$x + y = W$ (the weight of the body)
$\dfrac{x}{s} + \dfrac{y}{s} = V$ (the volume of the body determined by dipping it in water contained in a graduated vessel). From these equations x and y can be determined.

27. Equilibrium of immersed and floating bodies. —Since any body immersed in a fluid displaces exactly its own bulk of fluid and the force with which it is buoyed up is equal to the weight of the fluid displaced, it is evident that when the immersed body is denser than the fluid, it sinks in it, because its weight is greater than the floating power of the liquid. If the body be lighter than the liquid, the buoyancy of the liquid being greater than the weight of the body, it rises up until it displaces a weight of liquid equal to its own. It is then said to *float.* If the density of the body be the same as that of the liquid the weight of the body being equal to the floating power of the liquid, it remains in suspension in any position in the liquid. The *buoyant property* of liquids is *independent of their depth* or *expanse* for if there be only enough of water to surround an object plunged into it, the object will float as effectually as if it had been immersed in a large mass of water.

28. Application of buoyancy—This buoyancy of water is applied to practice in raising objects sunk in the sea, or removing wooden piles employed to keep out water during the construction of a dock. *Lighters* or hollow vessels are moored over them and filled with water. They are then fastened to these piles or objects by iron chains and the water is pumped out of the lighter. As the pumping proceeds the lighter is lifted and the pile or the immersed body is forcibly pulled on. It has also been applied in constructing *camels*, *i.e.*, instruments for carrying a ship over the bar of a river. It consists of a number of water-tight chests which are filled with water, placed in pairs on opposite sides of a ship and attached to it, or to each other by chains passing under the keel. If the water be then pumped out the vessel will be lifted and may be towed over the bar into deep water. The lifting power of the camel is the weight of the water displaced by the chests diminished by the weight of the whole apparatus. A *body denser than any liquid may* be made to *float on it* by giving it such a shape as to displace a volume of liquid whose weight is greater than its own. Iron pans, ships, porcelain saucers, are examples.

29. Cartesian Diver.—This toy shows each of the different cases of suspension, immersion, and floating that can present themselves when a body is placed in a liquid. It consists of a hollow glass ball, at the bottom of which is a small opening; a little porcelain figure is attached to the ball and the whole just floats upon water contained in a glass vessel almost filled with it, the mouth of which is closed by a piece of India rubber or a bladder. In this position the weight of the system is equal to the weight of the water displaced. If the bladder is then pressed by the hand, the air is compressed: this pressure is transmitted through the water to the air in the ball and a little water enters into the ball. The system now displaces less bulk of water, *i.e.*, the upward pressure is diminished but its weight remaining the same as before, the downward force becomes greater and consequently, the figure sinks. When the pressure is removed, this excess quantity of water flows out of the ball, the upward force is again increased and the figure rises to the surface. Most fishes and some birds have air bladders below the spines which they can compress or dilate at pleasure by muscular effort, and thus they can rise or sink in water or air.

30. From the foregoing phenomena it is manifest that the *leading features* in the nature of *liquids* are :—(1) Equality of pressure in all directions. (2) Pressure of liquid is proportional to its vertical height, and its area at the base, independent of the quantity. (3) A uniform levelness of surface in every connected mass of water, whatever be its magnitude or shape.

31. Specific gravity.—The specific gravity of a body expresses the number giving the ratio of the weight of a certain volume of the body, compared with the weight of the same volume of the standard substance, *i.e.* distilled water at 4° C. There are *three methods* of determining the specific gravities of solids and liquids ; (1). That of **Hydrostatic balance**. (2). That of **Hydrometer**. (3). That of **specific gravity flask**.

Hydrostatic balance method—The first method has already been described in Art 25.

According to this method the sp. gr. of a body is determined from the formula $\frac{w}{w-w'}$ where w is the wt. of the body in air and w' its wt. in water.

EXAMPLES.—(1) A piece of iron was found to weigh 115.5 gm. in air and 100.5 gm. when immersed in water, determine its sp. gr. Here $w = 115.5$; $w' = 100.5$. $\therefore\ w - w' = 15$.

$$\therefore \text{ Sp. gr. } = \frac{w}{w-w'} = \frac{115{\cdot}5}{15} = 7{\cdot}7.$$

(2) A substance weighs 50.5 gm. in air and loses 6. gm. of its weight when immersed in water. What is its sp. gr. ?—8.4.

The *volume of* an *irregularly-shaped body* may also be *determined by this method* by weighing the body in water and observing the loss of weight it sustains. As this is equal to the weighs of the water displaced by the body, the volume of the water givet the volume of the body.

EXAMPLE.—An irregular solid is found to weigh 98 gm. in vacuo and 64 gm. in water. What is its volume ?

(*N.B.* wt. of 1 c.c.m. of water = 1 gram.)

Here the loss of wt. = 98 − 64 = 34 grm.

∴ The wt. of the same volume of water is 34 grams. But we know that the wt. of one cubic centimetre (1ccm) of water is one gm.

∴ The volume of the water displaced by the body = 34 c.c.m.

∴ The vol. of the body = 34 c.c.m.

(*a*). **Hydrometer method**—There are several kinds of hydrometers, but *Nicholson's Hydrometer* is one that is used in determining specific gravities of solids and liquids. It consists of a hollow metallic vessel supporting a cup by a very thin stem [which is often a steel wire] and having attached to it a heavy cone, the object of the latter is to lower the centre of gravity so that the vessel does not upset when in the liquid. On the stem there is a well defined mark. To *Determine* the *specific gravity*—Suppose the weight w is required to be placed at the top to make the instrument sink up to the mark. Now place on the top a little quantity [less than w] of the body whose specific gravity is to be determined and let w' be the weight now required to make it sink up to the mark. Then $w - w'$ = weight of the substance.

Then place the body on the cone within the liquid, and let w'' be the weight required to be *added to the former weight* to make it sink up to the same point.

Then w'' = weight lost by the body in water = weight of the same volume of water. ∴ Specific gravity of the body $= \frac{w - w'}{w''}$

EXAMPLES. 1.—A Nicholson's hydrometer required 13.19 gm., or a piece of rock-crystal on the upper pan and 9.77 gm ; or the same piece of rock-crystal on the lower pan and 11.07 gm. to sink it. Determine the specific gravity of the crystal.

Here $w = 13.19$; $w' = 9.77$;

∴ Wt. of the body $= w - w' = 13.19 - 9.77 = 3.42$; w'' = The wt. added to the former wt. $= 11.07 \text{-} 9.77 = 1.30$. This is equal to the wt. lost by the body in water *i.e.*, the wt. of the same volume of water

∴ Sp. gr. $\frac{w - w'}{w''} = \frac{3.42}{1.3} = 2.63$.

2. A Nicholson's hydrometer requires 20 gm. to sink it. A crystal of galena is placed in the upper pan and 5.2 gm. to sink it to the same point. When the galena is in the lower pan 7.2 gm. are required. Find the sp. gr. of the galena. 7.4

(*b*). **Gravity flask method**—*The method of specific gravity* bottle is *used* chiefly in determining the specific gravities of *bodies* in the *powdered* state. It consists of a wide-mouthed flask filled with water and covered with a ground glass.

In this method the body whose specific gravity is to be determined is first weighed and then the flask is filled with water and weighed. Next the body is placed in the flask which is then filled with water and weighed again. Now when the body is introduced into the flask, it occupies a portion of the flask, therefore the water that is now required to fill the flask is *less* than the water which filled it before *by the* volume of the body that has been introduced.

1st observation gives the weight of the body $= w$ (suppose)

2nd observation gives the weight of the flask and the water which fills it $= w_1$

3rd observation gives the weight of the flask, *plus* the weight of the body, *plus* the weight of the water which filled the flask before, *minus* the weight of the water displaced by the body $= w_2$

Let F be the weight of the Flask

W " " " water which fills the flask before the introduction of the body.

We have—

w = the wt of the body

$w_1 = F + W$

$w_2 = F + w + W -$ the weight of the water displaced by the body.

$\therefore$ the wt. of the water displaced by the body

$$= F + w + W - w_2$$
$$= w_1 + w - w_2$$

$$\therefore \quad \text{Sp gr} = \frac{w}{w_1 + w - w_2}$$

EXAMPLES.—1. A sp. gr. bottle was found to weigh 39.74 gm. when filled with water, 40.37 gm. of lead shot was introduced and filling up with water, the weight of the bottle was found to be 76.54 gm. What is the sp. gr. of the shot?

Here $w = 40.37$; $w_1 = 39.74$; $w_2 = 76.54$

$\therefore \quad w_1 + w - w_2 = 3.57$ sp. gr. $= \frac{4037}{357} = 11.4$

2. A sp. gr. bottle was found to weigh 48.32 gm. when filled with water ; 12.8 gm. of a body was introduced into the flask and after filling it with water was weighed again ; the weight in the second case was found to be 54.76 gm. Determine the sp. gr. of the body. 2 nearly.

32. Specific gravity of liquids.—These are determined by the same methods as those employed for solids. (1) **Hydrostatic balance**. In order to determine the specific gravity of a liquid by this method a body of known weight, which is neither soluble in the liquid nor in water, is first weighed in water and then in the liquid, Let w be the weight of the body in air, and w_1 its weight in water; then $w - w_1 = wt$ of the water which the body displaces.

Again let w_2 be its weight in the liquid; then $w - w_2 = wt$ of the same volume of the liquid.

$$\therefore \text{ Specific gravity of the liquid} = \frac{w - w_2}{w - w_1}$$

EXAMPLES.—1. A body weighs 100 gm. in vacuo, 84 gm. in water and 74 gm. in another liquid. What is the sp. gr. of the liquid? 1.6

Here $w - w_1 = 100 - 84 = 16$ gm = the wt. of the water displaced by the body.

$w - w_2 = 100 - 74 = 26$ gm. = the wt. of the liquid displaced by the body. $\therefore$ Sp. gr $= \frac{26}{16} = 1.6$

2. The weight of a body is 250 gm. It loses 50 gm. when weighed in water and 75 gm., in a solution. Find the sp. gr. of the solution. 1.5

(2) **Hydrometer.**—The hydrometer that is used to determine the specific gravity of a liquid is **Fahrenheit's hydrometer.** It is constructed on the same principle as that of Nicholson's hydrometer, but it is made of glass so as to be used in all liquids and instead of a cone at its lower extremity a bulb loaded with mercury is used. To determine the specific gravity the instrument is weighed first and let its weight be w; it is then placed in water and let w_1 be the weight required to be placed in the upper pan to make it sink up to the mark.

Then $w + w_1 = wt.$ of the water displaced by the instrument.

It is then placed in the liquid whose specific gravity is to be determined, and let w_2 be the weight required to make it sink up to the same point.

Then $w + w_2 = wt.$ of the same volume of the displaced liquid.

$$\therefore \text{ Specific gravity of the liquid} = \frac{w + w_2}{w + w_1}$$

EXAMPLES.—1. A Nicholson's hydrometer, when floating in water required a weight of .15 gm. to be placed upon the upper dish in order to make it sink to a fixed mark on the stem; and 5.72 gm. had to be placed upon the dish to make it sink to the same mark in a solution of salt. The weight of the hydrometer was 94.47 gm. What was the sp. gr. of the solution?

Here $w = 94.47$ = the wt. of the instrument; $w + w_1 = 94.47 + .15 = 94.62$ = wt. of the water displaced by the instrument; $w + w_2 = 94.47 + 5.72 = 100.19$ = wt, of the liquid displaced by the instrument.

$\therefore$ Sp. gr. $= \frac{100.19}{94.62} = 1.06.$

2. The wt. of a hydrometer is 82.54 gm. It requires 2.12 gm. to be placed on the upper pan to sink it in water, and 18.74 gm. when placed in a solution. Determine the sp. gr. of the solution. 1.17

(3) **Gravity bottle.**—To determine the specific gravity by *specific gravity bottle*, it is first weighed empty, then full of water, and afterwards full of the liquid to be determined. The difference of the first two weighings gives the weight of the water and that of the first and the third weighing gives the weight of the same volume of the liquid. Hence the specific gravity is determined.

Let w be the *wt.* of the empty flask
w_1 „ „ „ flask filled with water.
w_2 „ „ „ „ „ liquid.
Then $w_1 - w =$ the *wt.* of the water which fills the flask.
$w_2 - w =$ The *wt.* of the liquid which fills the flask.

$\therefore$ Sp. gr. $\frac{w_2 - w}{w_{\text{[illegible]}} - w}$

EXAMPLES.—1. Determine the sp. gr. of a solution from the following data :—wt. of empty bottle $= 15.05$ gm ; wt. of bottle and water $= 61.5$; wt. of bottle and solution $= 57.45$ gm.

Here $w = 15.05$; $w_1 = 61.5$; $w_2 = 57.45$
$w_1 - w = 61.5 - 15.05 = 46.45$
$w_2 - w = 57.45 - 15.05 = 42.40$
$\therefore$ Sp. gr. $= \frac{42.4}{46.45} = .9.$

2. The wt. of a gravity flask is 20.56. gm. and its wts. when filled with water and the liquid are 85.32 and 102.64 gm. respectively. Determine the sp. gr. of the liquid. 1.26

33. Universal hydrometers—Hydrometers that have been already described are always made to sink up to the same extent by different weights placed on the upper pan., so they are called hydrometers of *constant volume but variable* weight. But universal hydrometers are those of *variable volume but of constant weight.* They are known under the different names of alcoholometer, lactometer, saccharometer, according to the purpose they serve.

QUESTIONS.

1. Define "Physics." How do you distinguish a *physical* phenomenon from a *chemical* one ? (1.)

State clearly the *domain* of physical science. Define *matter*, *mass* and *density*. (2)

Distinguish an *elementary* body from a *compound.* State briefly the *atomic theory*; define "atom" and "molecule." (3.4)

2. Enumerate the different forces that hold together the molecules of a body. How do you distinguish cohesion from chemical affinity ? (5)

3. What do you understand by *property of matter*. Distinguish *physical properties* from *chemical* ones. (6) What are general properties of matter ? Give proofs of each. (8) How can you determine the volume of an irregularly shaped body ? (8) How can you prove that liquids are porous. (8) Name the different physical states in which matter exists (7.)

4. Enumerate the special properties of solids (9) and liquids. (10) What do you know about the internal constitution of matter ?

5. Describe *Piezometer* and show how you can prove the compressibility of a liquid by means of this (10).

6. Enunciate and prove "Pascal's law." What do you understand by "the law of equality of pressures." (11)

7. Experimentally demonstrate (a) the upward (14), (b) the downward, (15) and (c) the lateral pressure of a liquid. (13). Describe Barker's mill (13).

8. Explain the construction of the Hydraulic Press. (12) Enunciate and prove the principle called the *hydrostatic paradox* (16).

9. Experimentally demonstrate that the pressure of a liquid at rest is the same at all points in the same horizontal line. (17) State the conditions of equilibrium of a liquid at rest (18).

10. What do you understand by the expression *that liquids maintain their own level* ? Prove that if two different liquids are poured in two communicating vessels, the *heights* of free surfaces will be *inversely* proportional to their *densities* (20). State the condition of equilibrium of several liquids placed one upon another in a phial. (21).

11. Define *level* and distinguish *true* from *apparent* level (19). Describe instruments called *water-level* (23) and *spirit level* (24). Show how you can determine the level of a place by the latter (24). Explain the principle of *Artesian wells* (22).

12. Prove that an immersed body loses its weight equal to the weight of the water displaced. Describe *hydrostatic balance* and show how you can determine the specific gravity of a body by this instrument (25). How can the volume of an irregularly shaped body be determined by this method ? (31).

How can you apply Archimedes' principle to determine the intrinsic value of gold and the quantities of impurities present ? (26).

13. State the laws of equilibrium of floating and immersed bodies (27). How are they applied to *lighters* and *camels* ? (28). Explain the action of the toy called *cartesian diver* (29).

14. What are the leading features that you observe in the nature of liquids ? (30).

15. Define Specific gravity, and describe the different methods employed to determine it (i) in case of solids (31. *a. b*). (ii) in case of liquids(32).

[1.] State the conditions which must be fulfilled in order that a body may float in equilibrium in a liquid ; and show that if a homogeneous body of volume v and sp. gr s floats in a liquid of sp. gr. s_1 ; the vol of the part immersed will be $\frac{v \cdot s}{s_1}$.

[2.] A solid body weighing 100 gm. loses 20 gm. of its weight in water; what is its volume ?

[3.] The sp. gr. of ice is ·918 and that of sea water 1·03. Determine the volume of ice that will be above the water when a block floats.

GASES.

34. Specific properties of Gases—Besides the general properties of matter, gaseous bodies possess the peculiar property of *self-expansibility*, called also its *tension* or *elastic force*, in virtue of which they always tend to occupy a greater space. This tendency to indefinite expansion is the only property by which they may be distinguished from liquids. In the molecules of bodies in the gaseous state the repulsive force is greater than the molecular attraction. If by low temperature and pressure the molecular attraction be increased, the gaseous body may be converted into liquid or even into solid. On the other hand, by means of heat, which acts in a contrary direction to the force of molecular attraction, a solid or a liquid may be converted into a gaseous state. *Vapour* is the term used to denote the aeriform state of bodies that remain in the solid or liquid state at the ordinary temperature. Ordinary atmospheric air is the body that is taken always as the type of all gases, as water is that of liquids. Therefore to determine the properties of gases all the experiments are performed in air.

35. Atmosphere.—It is the gaseous envelope surrounding the earth. It is composed of two elementary gases, oxygen and nitrogen; the former supports combustion and animal life, but the latter is chemically inert and serves to dilute the oxygen present, and without which oxygen would have exhausted animal life too rapidly. Besides these two gases the atmosphere contains carbonic acid gas, ammonia gas, and aqueous vapour. It is inodorous, transparent, and colourless in small masses. In large masses it is blue, and thus arises the blue colour of the sky. It serves as the medium for transmitting sounds. Its existence is proved by the winds, which blow incessantly on the surface of the earth, by the flight of birds, and by the suspension of clouds &c.

36. Properties of gases—Self-expansibility. This property of a gas is proved by taking a bladder containing a little air, closing the mouth and placing it within the receiver of an air pump. When the receiver is partly exhausted of air, the bladder distends. Before the experiment the air within the bladder exerted pressure equal and contrary to that exerted by the air outside; but when the external pressure is reduced by exhausting the receiver, the internal pressure of the air within the bladder prevails.

That *the air has weight* may be proved by taking a glass globe provided with a stopcock. If it is first weighed when full of air, then fitted into an air pump, and the air pumped out; when it is weighed a second time, its weight will be less; thus proving that the air has weight, which in this case is equal to the difference of the two weighings. The whole mass of air which constitutes the atmosphere then must exert certain pressure on the surface of the earth and on all bodies on it. This is called the atmospheric pressure.

37. Downward pressure, Magadeburg Hemispheres.—To *prove the downward pressure of the atmosphere* a piece of India-rubber sheet is tied air-tight to one end of a glass cylinder open at both ends, the other end is well greased and pressed on the plate of an air-pump. In this position the rubber sheet remains quite horizontal, since the upward pressure exerted on its lower face by the air within the cylinder is equal to the *downward* pressure exerted on its upper face by the air outside. If the air is pumped out of the vessel, the upward pressure of the air within will be diminished, and the rubber sheet will be pressed down by the pressure of the atmosphere above it and will finally give way with a loud report by the sudden entrance of the air. That this *atmospheric pressure acts in every direction* may be proved by *Magdeburg Hemispheres.* It consists of two hollow brass hemispheres fitting each other very accurately. The hemisphere which can be screwed on the *Airpump* is provided with a stopcock and the other which fits into the former is provided with a handle. As long as there is air within them they can be easily separated, for the external pressure of the atmosphere is counter-balanced by the pressure of the air within. When the air is pumped out the internal counteracting force is considerably diminished, and consequently a very great force is required to separate them. As this is the case in whatever position they are held, it follows that the atmospheric pressure is exerted in all directions.

38. Upward pressure—That the atmospheric *pressure* is exerted or transmitted *upwards* may be proved by taking a glass filled with water and covering it with a paper-disc. If the glass is then inverted, taking care that not a single bubble of air enters into it, it will be observed that the water does not come out; here the column of water is supported by the upward pressure of the atmosphere. This may also be proved by taking a long narrow tube open at both ends and dipping it in a liquid; if the top is then closed by the thumb, it will be observed that on taking the tube out of the liquid, the latter does not fall down though the lower end is open.

BAROMETERS.

39. Torricellian experiment—We owe to Torricelli an experiment which plainly shews the pressure of the atmosphere and enables us to estimate its intensity with great precision. A glass tube about a quarter of an inch in diameter and a yard in length is filled with mercury, the open end is stopped by the thumb and the tube is placed inverted in a vessel filled with mercury. If the finger is now removed, the mercury will descend in the tube, and after a few oscillations will remain stationary at a height which varies according to circumstances, but which is generally about 30 inches at the sea-level. The space between the closed end or the top of the tube, and the free surface of mercury in it is called *Torricelli's vacuum.* It is filled with mercury vapour only. The column of mercury is maintained at this height by the pressure of the atmosphere upon the surface of mercury in the vessel; for if the vessel with the tube be placed under the receiver of an *Air-pump* and the air is gradually pumped out, the mercury column will be seen to descend. Hence *every surface exposed to the atmosphere* sustains a normal pressure equal, on an average, to the weight of a column of mercury whose base is the surface itself and whose height is 30 inches.

40. The pressure "one atmosphere". From this law the *pressure "one atmosphere" i.e.*, that *exerted by the atmosphere at the sea-level on a unit area* may be easily calculated. Take a tube whose sectional area is a sq. inch. Since the column of mercury supported by the atmospheric pressure is 30 inches, the pressure on a sq. inch is then the weight of 30 cub. inches of mercury, which is equal to the weight of $13{\cdot}6 \times 30$ cubic inches of water. Now the weight of a cubic foot of water is 1000 ounces $\therefore$ the pressure of the atmosphere on a square inch is $= \frac{13.6 \times 30 \times 1000}{1728 \times 16} = 14.7$lbs. or in round numbers 15 lbs. It is evident from what has been stated that the pressure supported by the human body whose surface on an average is about 16sq ft. amounts to several tons. This pressure is exerted equally in every direction but it is not at all felt since the liquids contained in the organs as well as the solid parts of the skeleton resist it.

41. Pascal's Experiments. Homogeneous atmosphere.—Pascal repeated all the *experiments* performed by Toricelli and showed that the mercury column in the tube varies with the height of the place from the sea-level, as it should, if it were really *due to the atmospheric pressure which diminishes with the increase of distance* from the Earth's surface. He also showed that at the same level the height of the column is different for different liquids. In the case of water, whose density is $\frac{1}{13.59}$ th of mercury, the height of the column will be $13 \cdot 59 \times 30$ or about 34 feet. This is the maximum height to which water can be raised by the atmospheric pressure. From this column of mercury in the tube the *height of the atmosphere*, assuming it *to be homogeneous throughout* can be easily calculated. Let h be the height in inches of the homogeneous atmosphere, d the density of air compared with water, then $h.\ d.$ is the atmospheric pressure which supports 13.6×30 times the weight of water. Therefore $h = \dfrac{13.6 \times 30}{d}$, but $d = \dfrac{1}{773}$ of water $\therefore h = 13.6 \times 30 \times 773$ inches = nearly 5 miles. In reality the limit is far greater than that, since the air being compressible gets rarefied as we ascend. The exact limit of the atmosphere is the point where the self-repulsive power of the molecules is equal to the attraction of gravity.

42. Barometer.—Is an instrument used *to measure the pressure of the atmosphere.* In its simplest form it consists of a tube filled with mercury and placed inverted in a trough of mercury. The column of mercury within the tube indicates atmospheric pressure, and from the variation of which changes of atmospheric pressure can be easily determined. The amount of variation may be measured by graduation on the stem or on the board attached to it, the zero of the scale corresponding to the level of the mercury in the vessel. There are two kinds of barometers, *cistern*, and *siphon.* The Cistern Barometer is a modified form of what is described above, instead of a trough it has a pear-shaped vessel. The Siphon Barometer consists of a bent glass tube, one of the legs of which is much longer than the other. The longer leg which is closed at the top is filled with mercury while the shorter one serves as the cistern. The difference of the levels of mercury in the two legs gives the height of the barometer; and since these two legs communicate with each other, the pressure in the same horizontal line must be the same. The pressure on the free surface of mercury in the open branch is one atmosphere, therefore the pressure in the closed branch in the same level must also be one atmosphere, but this is equal to the column of mercury above that level. Hence this column above the level of mercury in the open branch indicates the barometric height. The *wheel barometer* is a siphon barometer, in the shorter leg of which there is a float. A string attached to the float passes round a pully and at its other end there is another lighter weight. A needle fixed to the pully moves round a graduated circle on which is marked the state of weather (variable, rainy, stormy, &c). When the pressure varies, the height of the column of mercury in the closed tube changes, and consequently the free surface in the open branch rises or falls with the float, and the needle is moved round to the corresponding points on the scale.

43. Their uses.—Barometers are used (1) to determine the heights of mountains or of places from the sea-level ; (2) to indicate changes of the weather.

a. As the atmospheric pressure decreases the ***higher*** we ascend, the mercury of the barometer will gradually *fall.* Hence observing the barometric column at the sea-level and at the place whose height is to be determined, the ***height can be calculated*** from the difference of these indications.

b. Again when air is filled with *aqueous vapour*, it becomes *lighter* and the mercury column stands *low.* When the air is *dry* and free from vapour, it becomes *heavier* than usual ; and the mercury stands *high.* Thus the barometer (by showing variations in the weight of the air, indicates when the air is *moist* and likely to rain or not. Also when the air is *cold*, it becomes *heavy* and the mercury stands *high* ; when it is *hot*, the mercury stands *low.* Hence the *barometer rises* most when the air is *cold and dry* and it *falls most* when the air is *moist* and *hot.* When the mercury is in a *rising* state, fine weather is at hand ; but when it is in a sinking state *foul* weather is near.

44. Boyle or Mariotte's Law—*The temperature remaining the same, the volume of a given quantity of gas varies inversely as the pressure which it bears.* This is verified by means of a bent glass tube, the shorter branch of which can have its end closed. It is fixed to a vertical and graduated stand, the graduation indicating equal capacities. A small quantity of mercury is poured into the tube until the level in both branches is at zero. The air in the shorter level being now under the ordinary atmospheric pressure, the end is closed, and mercury is poured into the longer tube. The volume of the air in the shorter leg is gradually diminished and when it will be half of what it was before, the column of mercury in the longer tube, above the level of that in the shorter one, will be found to be equal to the barometric column at the time. Before the experiment the pressure exerted by the air in the shorter leg was *one atmosphere.* Now the pressure on the free surface of mercury in that leg is equal to that of the mercury on a point at the same level in the longer branch. This latter pressure is equal to the atmospheric pressure on the free surface in this tube *plus* the weight of the column of mercury above the point, which is also equal to one atmosphere, so the pressure has been doubled and the volume is reduced to one-half. Similarly by increasing the pressure three times, the volume may be reduced to one-third, and so on. This *proves the law for compression. a.* To *prove it for dilatation, i.e.,* for pressures less than one atmosphere, use a bent tube of which both branches are long and pour in mercury to a certain height. Then close the one end and draw out some mercury from the other branch until the volume of air in the closed branch is doubled. Now the level of the mercury in the open branch is below that in the closed one, and their *difference* will be *half the barometric height.* The pressure of the dilated air *plus* half the barometric height is equal one atmosphere (which is the pressure on the free surface in the open branch. Therefore the pressure of the dilated air is half the barometric height. Thus when the volume is doubled the pressure is reduced to one half. Similarly it may be shown that when the volume is increased three times, the pressure will be reduced to one third and so on. This law is sometimes enunciated thus: *For the same temperature the density of a gas is proportional to its pressure.* In each case care must be taken to have the temperatures and barometric pressures the same at the beginning and at the conclusion of the experiment. This law is not absolutely true for all gases at all pressures but for ordinary pressures it may be assumed to be true.

.**Formula**—$V. P. =$ constant *i.e.,* if v be the volume of the gas where the pressure is p; if the pressure changes to p^1, the volume will be changed to v^1 such that so long as the temperature remains constant $v.p = v^1 p^1$

EXAMPLES.

1. A gas occupies 640 c. cm. when the barometer stands at 70 c.m. what will be its volume at the normal pressure (*i.e.*, at 76cm.)?

From Boyle's law we get $v.p = v'.p' \therefore 640 \times 70 = v' \times 76$

$$\therefore v' = \frac{640 \times 70}{76} = 590 \text{ nearly.}$$

2. A gas was found to measure 146·5 c.cm. when the barometer stood at 780 m. m. Afterwards the volume is found to be 159.5 c. c.m. what is the barometric height?

N.B. If v be the volume of the gas and d its density, the mass $= v.d.$ Since when the gas is compressed its mass remains unchanged $v.d.$ is constant.

i.e., if v_1 and d_1 be the new volume and density of the same gas

$$v.d=v_1d_1 \quad \therefore \frac{v}{v_1}=\frac{d}{d_1}$$

But from Boyle's law $v.p=v^1p^1$ *i.e.* $\frac{v}{v_1}=\frac{p^1}{p}$

$$\therefore \quad \frac{p^1}{p}=\frac{d^1}{d} \text{...} (2)$$

i.e., so long as the temperature remains the same, the density of a gas varies directly as its pressure.

EXAMPLE.—1. The density of air is 1.293 at the normal pressure (*i.e.* at 76 c.m.) what will be its density when the barometer stands at 80 c.m.?

Here $p=76$; $d=1.293$; $p^1=80$;

$$\therefore \quad \frac{80}{76}=\frac{d^1}{1.299} \quad \therefore \quad d^1=\frac{80}{76}\times 1.293=1.361$$

2. A litre of air weighs 1.293 under the pressure 760 m.m., what will be its weight, when the pressure is reduced to 720. m.m? 1.225.

C.U. Question.—A bubble of air is formed 100 ft. below the surface of water. State approximately its volume on reaching the surface as compared with its original volume.

The bubble was originally under the pressure of one atmosphere *plus* that exerted by 100 ft. of water.

When the bubble comes to the surface, the pressure is reduced to *one atmosphere.*

according to Boyle's law

$$\frac{\text{new vol.}}{\text{original vol.}}=\frac{\text{1 atm}+\text{100 ft.}}{\text{1 atm.}}$$

Now the pressure of *one atmosphere* = the pressure exerted by a column of 33 ft. of water.

$$\therefore \quad \frac{\text{new vol.}}{\text{original vol.}}=\frac{33+100}{33}=\frac{133}{33}=4 \text{ nearly.}$$

45. Manometers.—They are instruments for measuring the elastic force of gases or vapours contained in a closed space. *This force* is generally *expressed* in units called *atmospheres.* The instrument generally consists of a bent tube containing mercury, the shorter branch of which is much wider than the longer one, and is connected with the vessel containing the gas or vapour. When the end of the longer branch is *open,* it is called an *open-air* manometer, when *closed,* a *compressed-air manometer.*

INSTRUMENTS DEPENDING ON THE PROPERTIES OF AIR.

46. Air-pump.—It is an instrument by which air can be partially exhausted from a given space. It was invented by Otto Guerick in 1650 and has since undergone many improvements. It consists of a glass or metal cylinder, called the *Barrel*, in which a piston works. The piston consists of a metallic disc which works air-tight and is provided with a rod, by means of which it may be driven in or out. *The piston* has an *opening* through it which is *closed* at the lower end by a *valve opening upwards*. The barrel communicates with a passage leading to the centre of a carefully polished brass surface called the *plate* of the air-pump. The entrance to the passage is closed by a strong *conical valve opening into the barrel.* (This valve is generally placed at the extremity of a metal rod passing through the piston head and working in it tightly so as to be carried up and down with the motion of the piston within a very narrow limit).

(a). The working of the instrument.—Suppose the piston is at the bottom of the barrel and is raised. The pressure above the valve at the bottom is diminished but the pressure below it, which is equal to that of the atmosphere, remains unchanged, consequently the valve opens and the air from the receiver rushes into the barrel. On lowering the piston, the air within the barrel being compressed, the valve at the bottom closes, but the valve in the piston head opens, and the air escapes. On raising the piston again, a portion of the air remaining in the receiver passes into the barrel, whence it escapes on pushing the piston down. Thus at every stroke of the piston, a portion of the air in the receiver is withdrawn but as the quantity of air removed at each stroke is only a fraction of the quantity, which was in the receiver at the beginning of the stroke, we can never produce a perfect vacuum.

47. The pumps that have been described above are called *Single-barrel pumps*. They labour under the disadvantage that no air is withdrawn during the down-stroke, and the piston after having exhausted the air from the barrel in the *up-stroke must descend* in order *to prepare for* the *next stroke*. To avoid this Hawksbee's *double-barrel pump* is frequently used. It consists of two stout barrels in which two pistons work. These pistons are fixed to two racks, *i. e.* toothed rods fitting into the edges of a toothed wheel (pinion) one on each side. The wheel is moved by a handle so that when one piston ascends the other descends. The barrels are connected by a pipe which opens into the receiver. From the description given above, the working of the instrument can be easily understood ; the two barrels here acting alternately, though the machine acts with one, the *advantage* is *that the down stroke is not spent idly.* While the piston in the one barrel descends and thus prepares it for the next stroke, the piston in the other ascends and thus exhausts the receiver, so that vacuum is produced more rapidly.

In order to *measure the degree of rarefaction* or the density of the air in the receiver, a sort of manometer called the *air-pump gauge* is used. These instruments are of many kinds, but that which is often used is called *the siphon gauge.* It consists of a bent glass tube the open end of which can be screwed on a pipe communicating with the receiver. The other end is closed, and the whole of the closed branch is filled with mercury which also occupies a small portion of the other. If the closed branch be shorter than the length of the ordinary barometric column it remains completely filled, but as the exhaustion proceeds mercury sinks in this branch and rises in the other. (Let h be the barometric height, d the density of air and x the difference of heights in the two tubes, the density of the gas in the receiver is equal to $\frac{d.x}{h}$)

C. U. Question.—The degree of exhaustion after a certain number of strokes is calculated as follows—

Let R be the capacity of the receiver including that of the pipe and *B*, that of the barrel. Suppose at first the piston is at *a*, the inner extremity of the barrel then the volume of the air is *R* and let *D* be its density. As the piston moves from *a* to *b*, the outer extremity (*i.e.*) is driven out, the gas within the receiver expands from R to R + B, consequently the density changes from D to D_1 (suppose). The mass remaining the same we have

$$D_1(R+B)=D.\ R\ \therefore\ D_1=\left(\frac{R}{R+B}\right)D$$

When the piston moves from *b* to *a* (*i.e.*, is driven in) the quantity B passes out (through the valve in the piston) but the density remains unaltered.

Therefore at the end of the 1st stroke there remains in the receiver the quantity R. whose density is D_1.

The piston is driven out for the 2nd time and *R* expands into R + B as before ; the density again changes from D_1 to D_2 such that $D_2\ (R+B)=D_1.\ R$...............(1)

This density will remain unchanged when the piston is driven in again, for the quantity *B* passes through the valve as before.

∴ The density at the end of the 2nd stroke

$$D_2 = \left(\frac{R}{R+B}\right) D_1 = \left(\frac{R}{R+B}\right)^2 D \text{ from } (1)$$

Similarly if D_3 be the density after three strokes

$$D_3 = \left(\frac{R}{R+B}\right)^3 D$$

After *n* strokes therefore the density D_n will be $\left(\frac{R}{R+B}\right)^n D$

It is obvious then that the *exhausion* is *never complete,* since *D* can be *Zero* only when *n* is *infinite.*

48. Artificial fountain in vacuo—may be produced in a glass vessel provided with a stopcock and a tubulure ; it is then exhausted and the stopcock closed. On opening the stopcock under water in an open vessel, water will be forced through the tube by the atmospheric pressure acting on the free surface of water. In vacuo fire is extinguished and animal dies, for both combustion and animal life require for their support oxygen present in the atmosphere. Also as the atmosphere contains many putrifying germs, food and meat can only be preserved in vessels exhausted of air. To effect this, bodies to be preserved are placed in closed tin vessels with a small hole in the lid. They are then heated in boiling water, the vapour produced during boiling escapes through this hole, driving away the whole of the air from the vessel. They are then hermetically closed by molten lead.

49. Condenser—It is an instrument used to compress air or any other gas into a vessel. It consists of a hollow cylinder, one end of which can be screwed into a vessel. Just near this end there is a *valve opening outwards into* the *receiver* , and at the end of the opening in the piston there is another *valve opening* inwards *into the cylinder. Its working*—Suppose the cylinder and the receiver to be filled with ordinary air, and the piston to be at the open end. Forcing the piston in, the air in the cylinder is compressed and, opening the valve at the end, is forced into the receiver. When the piston is drawn out the valve at the end is closed by the air in the receiver, and the valve at the piston head is opened by the outer air which flows in and fills the cylinder. This air is forced into the receiver at the next stroke, and at every succeeding stroke the same quantity of air (= the volume of the cylinder) is added to the receiver. From the arrangements of the valves in the cylinder it will be seen that it is an *air-pump reversed.* For in the *air-pump*, the air is withdrawn from the receiver and forced into the atmosphere, whereas in the *condenser*, the air is withdrawn from the *atmosphere* and forced into the receiver.

a. Besides the *uses* of the *air-pump* and the *condenser* in the laboratory they are variously employed *in* the *arts.* The former is employed by the sugar-refiners to lower the boiling point of the syrup, the latter by soda water manufacturers to force carbonic acid gas into the reservoir containing the liquid to be aerated. In the *air-gun* the bullet is projected by means of the compressed air which on pulling the trigger escapes into the barrel from a reservoir in which it has been artificially compressed by condensers.

50. Pumps—They are machines for raising water which have been known from very early ages. Their invention is generally ascribed to Ctesibius, teacher of the celebrated Hiero of Alexandria. They are chiefly divided into two classes, the *lifting pump* and the *forcing pump.* There is a *third kind* which is a *combination* of the *two* former.

The lift pump.—It consists of a cast iron cylindrical *pump barrel* traversed by a piston, and communicating by means of a smaller tube at the bottom called the *suction tube* with the water in any reservoir. At the junction of the tube with the barrel is a valve opening upward called the *suction valve.* There is an aperture *in the piston-head,* closed by *another valve* opening upwards, and there is a spout in the side of the barrel for the passage of raised water. *Its action*—Suppose the piston to be at the bottom of the barrel and the pump filled with atmospheric air, the level of water within the tube is the same as outside it. As the piston rises the atmospheric pressure keeps the piston-valve closed, but the air in the suction tube opens the suction valve and then expanding as the piston rises, its pressure is gradually diminished. Hence the atmospheric pressure on the surface of water outside the pump will force it up the tube until the pressure at the same level is the same. When the piston descends the suction valve closes, and the air in the barrel becoming compressed opens the valve in the piston and escapes through it. This process being repeated the water will at length ascend through the suction valve, and at the next descent of the piston, will be forced through the valve in the piston and lifted to the spout through which it will flow. The precaution to be taken is that the *suction valve must not be higher than the height of the water-barometer* (*i. e.* 33ft) *above the surface of water* in the reservoir, for then the atmospheric pressure will not be able to raise water into the pump, since it can raise water only through the height of the water-barometer.

51. Force pump.—In this pump the piston is solid and has no valve. There is no spout but an orifice in the side of the barrel near the bottom, and a tube connected with the orifice through which the water is forced. There are *two valves*, *one* the *suction valve* as before, and *the other* at the orifice *opening* outward *into the tube* leading out of the pump. When this pump is first set in motion it works as a common pump, the air at each descent of the piston being driven through the side valve and the water rising in the suction tube. When the water has risen into the barrel the piston descending forces it through the side valve, and when it ascends, the side valve closes and more water rises through the suction valve. This process being repeated, the water is forced upwards through the side tube. From what has been said it is evident that the *stream* of water *cannot be continuous, for the water rises* in the side tube *when the piston descends.* A *continuous flow* may be obtained *by* arranging *two pumps*, both forcing water into the same pipe, and *working* in such a manner that when *one* piston *ascends* the *other descends.* A *continuous* although varying *flow* may also be obtained *by using an air-vessel or air-chamber connected with* the *side orifice* of the pump out of which the delivery tube passes. In this case the water is first forced into the air vessel, and the air in the upper part being compressed exerts a varying but continuous pressure on the surface of water within it, and thus the water is continuously forced through it. In the *fire engine these two systems* for producing continuous flow *are combined.* It consists of a pair of force pumps connected with an air-vessel, the pistons of which are worked by means of a lever so that while the one ascends the other descends.

52. Siphon.—It is an important practical illustration of atmospheric pressure, for in it a liquid under the combined action of *gravity* and *atmospheric pressure* flows first up-hill and then down-hill, but always in such a way as to bring the liquid from a higher to a lower level. It is simply a bent tube open at both ends and with *unequal lengths* When filled with water, the ends are closed and then the siphon is inverted and one end placed in water, the other end being below the surface of water. If the end within the water be opened it is clear that the pressure *at* *the other end* which is below the surface of water, is *greater than the atmospheric pressure.* Hence if this end be now opened, the water will begin to flow out and by so doing diminish the pressure in the tube and tends to form a vacuum in its upper part. If *the height of the bend of the siphon* from the surface of water be *less* than the *height of the water-barometer*, the *atmospheric pressure will force the water up* the tube and maintain a continuous flow through the end, until either the surface has fallen below the end dipped in water, or it has descended so far that the height of the bend becomes greater than the height of the water-barometer. It *is used* in *removing liquid without disturbing* the sediment *it* contains. It is sometimes applied to practice in *draining marshes.*

53. Baroscope.—The principle of Archimedes being applicable to all fluids whether liquid or gas, the resultant of the whole of the atmospheric pressure on the surface of a body is equal to the weight of the air displaced, and as this pressure is exerted upwards, a body weighs less in air than in vacuo. The *real weight* of a body being equal to the *weight* of the body *in air plus that of the air displaced by it.* If two bodies weigh the same in air, that which has the greater bulk will have the greater real weight. So the real weight of a maund of cotton is greater than that of a maund of iron. The *apparent weight* (weight in air) of a body gradually *diminishes as the barometer rises*, because the weight of the displaced air increases with the rise of the barometer. The loss of weight in air is proved by an instrument called *baroscope.* It consists of an ordinary balance, the beam of which supports two balls of very *unequal* sizes which balance each other in the air. When the beam with the balls is placed within the receiver of an air-pump and the air exhausted, the larger ball sinks, showing thereby that its real weight is greater than that of the smaller one. From Archimedes' principle it follows that when a body is (as many gases are) lighter than an equal volume of air it will rise in the atmosphere.

54. Balloons are constructed on this principle.—They are hollow envelopes, spherical or otherwise, of light impermeable bodies usually made of silk covered with varnish. These enclose a very light gas (rarefied air, hydrogen, coal-gas &c,) so that the weight of the whole thing is much lighter than the air it displaces. Consequently the balloon is lifted by an upward force equal to the difference of its weight and that of the air displaced. The aeronaut sits on a sort of boat made of wicker work attached to the balloon. It terminates below in a kind of neck opening freely into the air, and at the top there is another opening in the inside, which is closed by a valve held by a spring ; a chord attached to the valve passing through the bottom comes within the reach of the aeronaut so that when he wishes to descend he opens the valve by means of the chord which allows the gas to escape, and the balloon descends. In order to check too rapid descents sand bags, that are taken by the aeronaut, are gradually emptied. The rate of descent is also regulated by an instrument called the *Parachute.* It is a kind of large umbrella with a hole at the top, from the circumference of which are hung chords attached to a car or to one end of the boat. When it is left to itself it opens out and the resistance of the air acting upon a large surface moderates the rate of descent. The hole at the top is essential to safety, as it affords a regular passage for air which would otherwise escape from time to time from under the edge of the Parachute, thus producing oscillations which might prove fatal. Balloons were first invented by Montgolfiers, and the first public experiment was made at Annonay in 1783. They will be useful when they can be guided but as yet all attempts made with this view have completely failed. In some recent wars, they were used with advantage in military reconnoitring.

55. Bellows.—They consist of a leathern bag provided with a valve opening inward and a tube leading out of it is called the nozzle. There are two pieces of boards attached to the two sides of the bag, the lower board remaining fixed. If the upper one is raised, the air enters through the valve and fills the bag. When the board is pressed down, the valve closes, the air is compressed and forced through the nozzle.

56. Scientific toys—Hiero's Fountain.—It consists of three vessels placed successively one above another, the uppermost one is an open vessel while the other two are closed. There are three tubes, one passing from the bottom of the uppermost to the interior of the lowest one close to its very bottom, the second tube from the top of the latter passes into the middle one close to its very top, the third tube passes through the bottom of the first vessel into the lower part of the middle one. The third tube having been taken out, the middle vessel is partly filled with water, the tube is replaced, and water poured into the open vessel. This water flows through the other opening into the lower vessel and expels the air, which is forced into the middle one, where it being compressed presses upon the surface of water there, which is thus forced through the third tube in a jet.

57. Intermittent fountain.—It depends upon the pressure and elastic force of the atmosphere. It consists of a stoppered glass globe provided with small efflux tubes. A glass tube open at both ends passes through the globe up to the top of it and extends below nearly to the bottom of the basin, where there is a small hole for the escape of the water. Suppose the globe to be partly filled with water, the basin being empty, water will flow from the efflux tubes while air will pass up, through the central tube to supply its place and keep its pressure constant. As the water issues from the efflux tubes much faster than it escapes through the opening in the basin, the level rises in the basin, till the lower end of the central tube is covered. Now the passage of the air being cut off, the pressure of the air in the upper part of the globe diminishes gradually as the water escapes through the efflux tubes, so that after a certain time the flow ceases, when the *pressure of the air in the globe plus that of the column of water* in the efflux tube is *equal* to or less than the *atmospheric pressure.* But as the water continues to escape from the basin through the opening, the bottom of the central tube is again uncovered, and the air entering into the globe, water again begins to issue from the efflux tubes, and the same changes are repeated.

58. Natural intermittent Springs.—In nature springs are met with whose flow is spontaneously interrupted and which begins after a certain interval. Their action depends upon the principle of the siphon. Suppose a reservoir to communicate with an outlet by a bent tube forming a siphon, and suppose it to be fed by a stream of water at a lower rate than the siphon is able to discharge it. When the height of the water in the reservoir has reached the bend, the siphon will begin to act and the reservoir will be emptied ; flow will then cease until the reservoir becomes charged up to the bend again. *Tantalus' cup* is an instrument constructed on this principle. It consists of a cup in which is a bent tube rising to a certain height and with the short branch terminating near the bottom of the cup, while the long branch passes through the bottom. When the level of the liquid poured into the cup rises above the bend of the siphon tube, the latter begins to discharge the liquid. Nowadays photographic work boxes for washing prints are constructed on this principle.

QUESTIONS.

C. U. Question.—A piece of cork is floating in a basin of water. If the basin be placed under the receiver of an air-pump and the air pumped out, prove that the cork will sink.

The condition of equilibrium is, the wt. of the cork (which is a downward force) is equal to the wt. of the water displaced by the cork, plus the wt. of the air displaced by it (the two latter are upward forces).

When the air is pumped out, the density of the air is diminished, consequently the wt. of the air displaced by the cork (which is an upward force) is diminished ; the wt. of the cork therefore becomes greater, consequently it sinks.

Let C be the wt. of the cork.
W_C ... ... water displaced by the cork.
A_C ... ... air displaced by the cork.

From what is stated above $C = W_C + A_C$.

But A_C diminishes as the air is pumped out, C (which is a downward force becomes greater and the cork sinks.

1. What are the special properties of gaseous bodies ? (34) Give experimental proofs of each. (36.) How can you prove that the atmosphere exerts pressure in all directions ? (37,38).

2. Describe Torricelli's experiment, (39) and calculate the pressure exerted by the atmosphere on a unit area. (40). What are the conclusions Pascal arrived at by repeating Torricelli's experiment ? (41.) How can the height of the atmosphere, assuming it to be homogeneous, be calculated. (41.)

3. Give the constructions of different kinds of barometer. (42.) What are their chief uses ? (43).

4. State and experimentally demonstrate Boyle's Law ; (44). and explain the nature of the limitations.

5. (a) Give a clear explanation of the statement that the mercury in a barometer tube is sustained by the atmospheric pressure. Why is mercury the liquid generally employed ? How is the mercury column affected (1) by the narrowness of the tube, (2) by the changes of temperature, (3) by the height of a place from the sea-level ?

(b) What is meant by Torricelli's vacuum ? What would occur if a puncture be made in the side of the barometer tube above the surface of mercury in it ?

(c) What would be the height of the water-barometer when the mercury barometor reads 30 inches ?

6. Give the construction of the air-pump and explain its working. (46). What are the advantages of a double barrel or Hawksbee's air-pump. (47). Give the construction of the apparatus by which the degree of rarefaction of the air in the receiver of the air-pump may be measured. Show how you can measure it. (46) Give the construction of the condenser, and shew that it is a mere reversed air-pump. (47). What are the uses of condensers and air-pumps in arts ? (49). How is an artificial fountain prepared in vacuo ? (48).

7. Explain the construction and action (1) of lift pump (50); (2) of force pump (51). How can the stream of water from the delivery tube in the force pump be made continuous? How are fire-engines constructed? State the use of the air-chamber in a fire-engine.

8. Explain the action and uses of the siphon. (52.) Describe the *baroscope*, and shew how the principle of Archimedes applies to gaseous bodies. (53).

9. Give the construction and uses of a balloon. (54) Explain the action of (1) Hiero's fountain (56); (2) intermittent fountain (57); (3) of Tantalus' Cup (57). Shew that the principle of Tantalus' cup applies to natural intermittent springs. (58)

FORCE.

1. Force.—*A force* is that which produces or tends to produce a change in the state of bodies from that of rest to that of motion, or *vice versa.* It is called a *power* when it produces *motion*, and *resistance* when it opposes motion. A body is said to be *at rest*, when it does not change its position with reference to neighbouring objects; it is *in motion* when it passes from one point to another *i.e.*, when at two succesive instants of time, it occupies two different positions in space. Both rest and motion may be *absolute* or *relative*. *Absolute* rest would be *entire* absence of motion. No such condition is known in the universe, for everything here is in motion. Relative or apparent rest is the condition of a body which appears fixed with reference to neighbouring bodies, but which really shares motion with them. For instance trees, houses &c. on the surface of the earth are in a state of rest with reference to it, but they are, with the earth itself, in a state of motion with respect to the celestial bodies. Relative motion and rest are alone presented to observation.

2. Motion.—There are *two things* that *determine* the *motion* of a particle; the *direction* in which the particle is moving, and the *rate* at which it is moving. *First* with regard to *direction*, a body may be moving in a straight line, *i.e.*, the direction of motion might remain unchanged, the motion is then said to be *rectilinear*; or secondly, the direction of motion of the body might change from instant to instant, in this case the body will describe a curved path, and the motion is then called *curvilinear*. *Secondly*, with regard to the *rate* at which a body moves. Let us suppose the direction of motion not to change *i.e.*, motion to take place in a straight line. Let a body move through the distance of 12 miles in 3 hours, then we say that the body is moving at the *rate of 4 miles* per hour. In Dynamics the term *velocity* is used to denote this rate. *Velocity* or the rate of mo-.

tion of a body then is the space traversed by it in a unit of time; It is said to be *uniform* when *equal* spaces are passed over in each unit of time, and *varied* when *unequal* spaces are traversed in equal times. *Acceleration* is the *change of velocity in unit of time.* It is said to be *uniform* when this *change* remains constant, *i. e.* the *same* for every unit of time, and the motion is then said to be *uniformly accelerated.* When the change of velocity is not constant, acceleration is said to be *varied.* The term acceleration with the negative sign is used for *retardation. Example*—When a train starts from the station its motion is first *accelerated,* after a time it becomes *uniform,* then as it approaches the next station it is gradually *retarded* or negatively accelerated.

3. Friction.—It consists in the obstacle to be overcome when one body slides over another or when a cylindrical body rolls over a plane surface. The first is called the *sliding friction,* the 2nd the *rolling friction.* The *latter* is *less* than the former, since in the first case one point on the surface of one body comes successively in contact with all the points in a line on the surface of the other body, whereas in *rolling friction* one point of the cylinder comes in contact with points in a line on the plane surface of bodies after a complete revolution of the cylindrical body. Friction is diminished by rubbing the surface with fatty matters. The surface of bodies are never perfectly smooth, even the smoothest possess roughness which cannot be detected by touch or by ordinary sight. Hence every body in the universe offers friction more or less. Even the hypothetical luminiferous ether offers resistance to the passage of heavenly bodies such as Enck's Comet.

4. Measurement of force.—There are *three things* that *determine* the *force* acting on a body: the point of application, the direction, and the intensity. The *point of application* of a force is the point at which it exerts its action; the *direction* of a force is the right line along which it moves or tends to move the point; the *intensity* of a force is its energy or magnitude with reference to a certain standard; the *unit of force* being that which *produces* the *unit velocity* when it acts momentarily on a *unit mass.*

Instruments for measuring force. The idea of force is usually obtained by our conscious exercise of muscular energy, and we can appoximately estimate the amount of a force by the effort which we have to make to resist it, as when we try the weight of a body by lifting it. *Dynamometers* are instruments used to measure force by means of its effect in bending or otherwise distorting the elastic springs, the *spring balance is usually the* *instrument applied*, in which the springs are either spirals or helices. Another form of dynamometers consists of a V-shaped plate of elastic steel, at the end of one arm of which is fixed an iron arc which passes freely through an aperture at the end of the second arm. There is another arc which is fixed to the end of the second arm and passes through an aperture at the end of the first. There is a graduation in one of the arcs, the force to be measured is attached to the end of one of the arcs, that of the other being fixed to a support. The numbers of graduation through which the arm to which the forces are applied are moved give the relative measurement of those forces.

A *force* may be *represented by a straight line* drawn from a certain point as the origin, so that its direction gives the direction of force, the number of units of length contained in it being equal to the number of units of force which it represents.

When a body is acted on by a single force it moves in the direction of this force, if not counteracted by anything else. The effect of a force upon a body is not altered by changing its point of application to any other point in its line of application. This is called the *transmissibility* of force.

If a body is acted on by several forces in different directions, the direction of motion of the body will *not* coincide with that of any of the forces. If two men pull a thing by means of ropes in two different directions, the thing will take an intermediate course, as if it were acted on by a single force in that direction. This force is called the *resultant force of* the two *former* that are called the *component forces* with reference to this resultant. If two forces acting on a body are *equal in magnitude*, the direction of motion of the body will *bisect* the angle formed by the directions of the two forces.

Thus it is seen that when two or more forces act at the same point on a body, it begins to move in one direction *i.e.*, it behaves as if it were acted upon by a single force acting in the direction in which the body moves. Therefore we can replace these forces by a single force which will produce the same effect as that produced by these forces. This process of finding a single force which is equal, in effect, to two or more forces is called the *composition of forces.* Also when one force acting on a body produces a certain effect, which is equal to the effect produced by two or more forces, we can substitute these forces for the single force. This operation of replacing a single force by two or more forces acting at the same point in different directions so as to produce the same effect is called the *resolution of forces.*

5. Parallelogram of forces—If two forces (P and Q) acting on a particle be represented in magnitude and direction by straight lines drawn from the particle, and a parallelogram be constructed, having these straight lines as adjacent sides, then the resultant R of the two forces is represented in magnitude and direction by that diagonal of the parallelogram which passes through the particle. This has been experimentally verified by *Gravesande's apparatus.* It consists of a light frame in the form of a parallelogram ABCD. Weights can be hung at points A, B, and C respectively, two of which, namely those at B and C are attached to the chords passing over two smooth pulleys. When these weights are proportional to AB, AC, AD respectively, the strings attached at B and C will be observed to form prolongations of the sides AB, AC and the diagonal will be vertical.

Also we know that if θ be the angle between AB and AC then $AD^2 = AB^2 + AC^2 + 2\ AB.\ AC.\ \text{Cos}\ \theta$.

But since these lines represent forces, we get

$$R^2 = P^2 + Q^2 + 2\ PQ.\ \text{Cos}\ \theta.$$

When $\theta^\circ = 90^\circ$ *i.e.*, when the forces are at right-angles to one another $R^2 = P^2 + Q^2$.

Many applications of the principle of the parallelogram of forces are often seen in every day occurrences. Thus in the flight of a bird when the wings strike against the air, a resistance is offered which is equal to two impulsive forces from back to front, and the resultant is a single force that makes the bird advance. Swimming is another instance of this.

If the two forces acting on the body are *not concurrent* but *parallel* they may act either in the *same* direction, as in the case of two horses drawing a carriage, then the resultant of the forces is equal to their sum ; or they may act in opposite directions as in the case of a steamer ascending a river, the current acting in opposition to the propelling force of the vessel, then the resultant is equal to the difference of the forces. *Condition of equilibrium of forces.*—When several forces acting on a body neutralize one another they are said to be in equilibrium. If *two* forces acting on a body are *equal in magnitude* and *opposite in direction,* they will be in equilibrium. If *three* forces act on a body, the condition of equilibrium is that they may be represented in magnitude and direction by the three sides of a triangle taken one way round. So if *any number of forces* acting on a particle keep it in equilibrium they may be represented in magnitude and way of action by the sides of a polygon taken in order.

6. Gravitation.—The term *gravitation* is used to denote the attractive force exerted by every material particle on every other particle. The *laws of gravitation are* :—1. For the *same distance* the *force* is *proportional* to the *product* of the *masses* of two *bodies.* 2. The masses being equal, the *force varies inversely* as the *square* of the *distance* between the particles. It is very difficult to demonstrate experimentally that bodies such as we can handle attract one another. This difficulty arises from the fact that the mass of bodies which we can handle is so small compared with that of the earth that even when we bring the bodies as near as we can, the attraction between them is an exceedingly small fraction of the weight of either. We cannot get rid of the attraction of the earth, so as to be able to measure the force of gravitation ; but Cavendish by means of an apparatus, similar to Coulomb's torsion balance, arranged the experiment in such a way that it interfered as little as possible with the effects of attraction of the other body.

Newton shewed that guided by this law heavenly bodies move in their orbits. *Gravity* is a *particular* case of gravitation. It *denotes the attraction exerted by the mass of the earth on all neighbouring bodies.* In virtue of this force all bodies *fall* to the earth when they are not supported by anything. The *weight* of the body denotes the magnitude of the force with which the mass of a body is attracted by the earth. Gravity being a particular case of gravitation, acts upon bodies *proportionally* to their masses and *inversely as the square of the distance.* Hence a body which contains twice or thrice as much matter as another, weighs twice or thrice as much. Again if the same body be moved twice or thrice its present distance from the centre of the earth, it would have one-fourth or one-ninth its present weight. As the different points on the surface of the earth are not equally distant from its centre it is evident that the *weight* of a body *varies* at *different* places on the *earth's surface.* Also the rotation of the earth about its axis gives rise to a (centrifugal) force acting on bodies on the earth's surface in a direction contrary to that of the force of gravity. This force varies at different places on the earth's surfaces and consequently the apparent weight of a body which is the resultant of this (variable) force and gravity, varies at different places. These two causes then contribute to the same effect and the *weight* of the body *increases from the equator to the poles.*

At any point on the earth's surface the direction of gravity, *i.e.*, the line which a falling body describes is the *vertical line.* Any plane perpendicular to this is *horizontal.* At each point on the earth's surface a man standing upright is in the direction of the vertical. The vertical line at any point of the globe is generally determined by the *plumb-line.* It consists of a cylindrical weight attached to a string which passes through a hole at the centre of a square piece of wood or metal, the side of which is equal to the diameter of the weight. To determine whether anything is vertical or not, the edge of the plate is placed against it; if now the weight *just* touches the object it is vertical, if not it is inclined.

7. **Centre of gravity.**—The centre of gravity of a body is the *point* on which the *resultant* of the earth's attractions on the molecules of the body (*i.e.*, the weight) *acts.* It is the point on which the body will balance in all positions supposing the point to be supported and the body to be acted on by gravity alone. In many cases it can be easily determined; for instance in a line this point is the point of bisection. In cylindrical bars it is the middle point of the axis. In the circle and the sphere it coincides with the geometrical centre. In almost all cases it is determined by suspending the body by a string in different positions. In the case of a *thin flat* body, it is suspended in *two* different positions, the C. G. is evidently in the prolongation of the vertical chord which supports it in *these two positions*, and consequently it is at the *point of intersection of the two lines.* If the body be *thicker three* positions must be found; the C. G. is at the point of intersection of the three planes passing vertically through the lines of contact when the body is in equilibrium in these positions.

When a body has only one point of support in order that it may remain in equilibrium the C. G. must either coincide with the point or remain in the same vertical line with it. If the body has two points of support the equilibrium is established when the C. G. is exactly above or below the right line joining the two points. It there are three or more points of support, equilibrium is produced when the C. G. is within the figure formed by these points of support.

The centre of gravity of a body always *tends to occupy the lowest possible position.* Therefore although the condition of equilibrium is that C. G. *must lie in the vertical line through the point of support*, the state of **equilibrium** may be **stable**, **unstable** or **neutral**. A body is said to be *in stable* equilibrium if after *slight disturbance it tends* to *return to its first position.* The pendulum of a clock is an example of this. The body is said to be in *unstable* equilibrium when the slightest *disturbance tends* to *deviate the body from its original position* of rest, as an egg standing on an end, a stick standing upright on its end. A body is in *neutral* equilibrium when it *remains at rest in any position* that may be given to it. When a body rests on a horizontal place, its state of equilibrium is stable when the vertical line through the point of support passes through a point *above* C. G. of the body ; it is *unstable* when the line falls *below* C. G. ; it is *neutral*, when the line passes through C. G. Thus the *lower* the C. G. of the body the *more stable* is its position. It follows from what has been said that the wider the base on which a body rests, the greater is its stability, for then even with a considerable inclination its C. G. or the vertical line through it remains within its base. In living beings the C. G. is not fixed but varies with their attitudes and the loads they support. Therefore it is often observed that a man to retain his stability, so modifies his attitude as to keep the C. G. directly above his feet. Thus a man with a load on his *back* is obliged to lean *forward* ; while carrying a load in one hand he is obliged to lean his body on the opposite side. In rope-dancing the performer, to keep the C. G. exactly above the rope, holds in his hands a long pole which, as soon as he feels himself leaning on the one side he inclines towards the opposite.

8. **The lever**—It is the name given to any inflexible bar, straight or curved, movable in one plane about a fixed point called the *fulcrum.* The forces acting on the lever are the *weight* or resistance, the *power* and the *reaction of the fulcrum.* Levers are divided into three classes, according to the positions of the points of application of the *power* and the *weight* with respect to the *fulcrum.* In a *lever of the first kind*, the *fulcrum* is *between* the *power* and the *resistance* ; as in an ordinary balance, in the Danish steelyard, in a poker, in a crowbar used to raise heavy weight and in the brake of the pump. In scissors, shears, nippers and pincers we have examples of a double lever of this class. In a lever of the *second kind*, the *resistance* is *between* the *power* and the *fulcrum.* The oar of a boat is an example of this kind ; the fulcrum is at the blade of the oar in the water, the power is applied by the hand and the resistance is applied at the row-lock. A wheel barrow also serves as an example. A pair of nut-crackers is a double lever of this class. In a lever of the *third kind*, the *power* is *between* the *fulcrum* and the *resistance*, as in the treadle of a lathe and in the pedals used in grind-stones. A pair of tongs used to hold a coal is a double ever of this class. The human forearm

employed to raise an object taken in the hand is another example. The fulcrum is at the elbow; the power is by a muscle which is inserted in the forearm near the elbow and weight is the object raised in the hand. In *the lever* the *power* is *to* the *weight* in the *inverse ratio of their arms*. (The *arms* being the distances of the points of application of the forces from the fulcrum.)

9. The balance—It is an instrument for determining the relative weights of bodies. The ordinary balance is a lever of the first kind. It consists of a beam with a scale suspended from each extremity. The beam can turn about a fulcrum which is *above* the C. G. of the system formed by the beam, scales, and the things which may be put in the scales. The fulcrum consists of a steel prism (knife edge,) passing through the beam and resting on a support. The substance to be weighed is placed in one scale and the weights in the other until the system is in equilibrium.

A *true* balance, *i.e.*, what gives exactly the weight of a body should *fulfil the following conditions* (i) the *two arms* of the *beam must be precisely equal;* otherwise according to the principle of the lever *unequal* weigts will produce equilibrium. We may test whether the arms are equal by observing whether the beam still remains at rest (i. e. in the horizontal position) when the contents of the scales are interchanged ; (ii) *the balance ought* to be in *equilibrium* when *the scales are empty* ; otherwise unequal weights will be required to produce equilibrium ; (iii) *the beam being horizontal* the *point of suspension must be a little above the C. G. of the system and* in the *same vertical* line with it. For it is in this position the beam remains in stable equilibrium ; and when disturbed it comes to this position after a certain number of oscillations. If C. G. *coincide* with the point of suspension the beam would be *neutral* and would not oscillate ; if C. G. be *above* the point of suspension it would be *unstable*, and a slight disturbance would cause it to deviate from this position.

A balance is said to be *delicate or sensible* when it can detect the small difference between the weights in the two scales. *Conditions* of *delicacy*. (1) The centre of gravity of the system should be *very near* the point of suspension. For when the beam is inclined its weight acts upon the arm of the lever which is equal to the distance of its C. G. from the point of suspension and offers resistance to the excess of the weight in one of the pans. This vanishes if C. G. of the beam coincides with the point of suspension. (2) The beam should be *light* and the knife-edge should de made as sharp as possible. The object of the latter is to reduce the friction of the edge on the support. (3) The beam should be made *long* ; the longer the beam the more delicate is the balance, for then the difference in the weights acts upon the longer arm of the lever and causes greater deviation.

The steelyard—It is another kind of balance in which the arms are unequal and the same weight is used to weigh different bodies by varying its distance from the fulcrum. It follows from the principle of the lever that the smaller weight acting through the longer arm is equivalent to the greater weight acting through the shorter arm, i. e. the weights are inversely proportional to the lengths of the arms.

10. Laws of falling bodies—[1] In a *vacuum* all *bodies fall with equal speed* ; [2] The *space* which a falling body traverses is *proportional* to the *square* of the *time during* which it has fallen ; [3] the *velocity* acquired by a falling body is *proportional* to the *duration* of its fall. The *first law is proved* by the *guinea and feather* experiment. The apparatus consists of a long glass cylinder with one of its ends completely closed and a brass stop-cock fixed to the other. After having introduced two bodies of different weights and densities [a peice of lead and a feather for instance,] the air is withdrawn and the stop-cock closed. If now the tube be suddenly reversed, or the two bodies let go simultaneously, the two bodies will be seen to fall *equally* rapidly. But if a little air be introduced into the tube the motion of the lighter will be obstructed. It follows from this that the *force of the earth which causes bodies to fall is exerted equally on all bodies*, but the *difference* in the *velocity* is due to the *resistance* of the air. The resistance of air in falling bodies is apparent in case of liquids, for in a vacuum liquids fall like solids without separation of their molecules. The *water hammer* is an example of this ; it consists of a tube partly filled with water, from which air has been expelled by boiling before closing the end. The two other laws are verified by *Atwood's machine.*

Inclined plane.—Proof of the 2nd law of falling bodies by means of is.—

When a *body* is *placed on* any *surface*, there are *two forces* that come into play, *one* due to *gravity* which always acts *vertically downwards*, and the *other* due to the resistance offered by the surface, which is always *prependicular to the surface at the point of contact.* When therefore the body rests on a *horizontal plane surface*, the action of *gravity* is *entirely counteracted by* the *resistance of* this *plane.* Since in this case the two forces act in the same line and in the opposite direction.

But when the body is placed on an *inclined plane* (*i,e.*, a plane surface more or less inclined to the horizon), the *resistance* of the plane (which is perpendicular to the plane), *cannot wholly* *counteract* the action of *gravity* (which is a force vertically downwards.) In this case the action of *gravity* is *decomposed* into *two forces*, *one prependicular* to the *plane* (which is counteracted by the resistances of the plane), and the other in the direction *parllel to* the *plane.* This *latter force* remains *un-opposed*, and when the surface is frictionless, it *makes the body descend along the plane.* The *value* of this force then *depends upon* the *degree* of inclination of the plane.

It may be proved that if W be the weight of the body placed on an inclined plane, and θ, the angle which the plane makes with the horizon, *the force which drives the body along the plane is* $W \sin\theta$. Hence when θ is *very small i.e.*, when the plane makes a *very small* angle with the horizon, the *force* which drives the body along the plane is *very small.* Thus, we see that the motion of a falling body may be retared to any desired extent, by altering the inclination of the plane.

This property of the inclined plane of slackening the motion of a falling body, has been used to *demonstrate the 2nd law of falling bodies*:—For this purpose, a smooth graduated plane is taken and placed inclined at a desired angle. An ivory ball is taken and is allowed to roll down the plane, first, from a position (which is found by trial), such that the ball just takes one second to reach the bottom of the plane. The ball is then allowed to roll down a second time, from another position, whose *distance* from the bottom of the plane is *four times* the *original* distance, it will be found that the time which the ball now takes to traverse this distance is *two seconds.* Similarly when the *distance* is increased *nine times* the ball will take *three* seconds to traverse it. Hence it is inferred that the *space* traversed by a falling body *is proportional* to the *square* of the *duration* of its fall.

Q. Prove that when a horse draws a cart on a *road* where there is *a rise of one in thirty*, it really lifts *one-thirtieth* of the load.

"A rise of one in thirty" means that when the *distance* between any *two points along* the inclined plane is 30 units of space, the *difference* of their vertical heights will be *one unit* only, so that when a body *passes over thirty units* of space *up* the plane, its *virtical ascent* is *one* unit only. Hence in this case θ, the inclination of the plane, is such that $\sin\theta = \frac{1}{30}$. If then W be the wt. of load, the force which drives this load along the road is $W \times \frac{1}{30}$. Now if we neglect friction, to keep the load in equilibrium, *the horse will have to exert* a *force equal* to $W \times \frac{1}{30}$.

$\therefore$ The *horse really lifts one-thirtieth of the load.* This explains why a road up a steep hill is made zigzag. The principle of the inclined plane is made use of in rolling a heavy body into or out of a waggon.

Pendulum.—A *pendulum* means a heavy particle suspended by a string the other end of which is fixed. In the position of equilibrium the string will be vertical. If the particle be displaced from this position, (the string being kept stretched) and then allowed to move, the particle will oscillate backwards and forwards, describing an arc of a circle; the arc continually diminishes owing to the resistance of the air until the particle comes to rest. Pendulums are of two kinds, *simple* and *compound.* A *simple one*, which has merely a theoretical existence, *consists of a material point suspended by a weightless string;* a *compound* one is anything which can oscillate about a fixed point or an axis.

Explanation.—When the pendulum is at rest the vertical line through the C. G. of the body passes through the point of suspension and the gravitating force is entirely counteracted by the tension of the string. When the ball is slightly displaced, the *gravitating force still remains vertical*, but the *tension* of the *string* is now *inclined* to the vertical line *by* the *angle through* which the *ball has been displaced.* Then *resolving* the gravitating force *along* the string and *perpendicular* to it, the former is counteracted by the *tension of the string*, and *the latter*, which is *proportional to the sine of the angle of displacement*, *brings it back to its original position.* As soon as the ball comes to this position, the *whole* of the gravitating force is counteracted; but owing to its previous motion it has acquired certain velocity which drives it to the other side. Again as it goes to the other side, the *same force* (*i.e.*, the component of gravity perpendicular to the string) tends to bring it back to the original position, so that its motion gradually diminishes until it stops and then again it comes back. This is repeated.

Laws of pendulum.—(1) *The oscillations of one and the same pendulum are isochronous i. e are effected in equal times. (2) The durations of oscillations are proportional to the square roots of the lengths of the pendulums. (3) If the length remains constant the duration of oscillation is independent of the substance of which the pendulum is formed. (4) The duration of oscillation of a given pendulum varies inversely as the square root of the force of gravity in the place in which it oscillates.*

Experimental proof.—The **1st law**, which was discovered by Galileo, may be *verified* by *counting* the *number of oscillations* made by a *pendulum* in *equal times* as the *amplitude varies.* This is found to be *constant* for *small angles* not exceeding 4 or 5 degrees. The **2nd law** may be proved by causing *several pendulums* whose *lengths* are as 2 4, 9 &c. to *oscillate simultaneously*; the corresponding *number of oscillations* in a given time are found to be as 1, ½, ⅓, &c. By taking several *pendulums* of *equal lengths* having *balls of different substances*, it is found that these *oscillate* in *equal times*; thus *proving the* **3rd law** and the fact that the *accelerating effect* of gravity on all bodies is the *same* at the *same place*. The **4th law** may be demonstrated by *taking* the *same pendulum* to *different parts of the earth* and counting the *number of oscillation* it makes in a given time. This *number* is found to *increase from the equator to the poles*. The force of gravity is also practically measured in this manner.

Amplitude is the chord of the arc described by the pendulum during a semi-oscillation.

The **length of a pendulum** is the distance between the point of suspension and the centre of gravity of the bob and the rod.

C. U. Question.—A second pendulum is about 39 inches long, what is the length of one which beats only once in three seconds ?

Let l be the length of the pendulum then it follows from the 2nd law of pendulum.

$$\frac{\text{duration of the 1st}}{\text{duration of the 2nd}} = \sqrt{\frac{39}{l}}$$

$$i.e.\ \tfrac{1}{3} = \sqrt{\frac{39}{l}}$$

$$\therefore\ \frac{39}{l} = \frac{1}{9} \text{ or } l = 351 \text{ in} = 29.25 \text{ ft.}$$

Motion in a circle.—Centrifugal force—When a body moves in a *circle* it is acted on by two forces; *one* acting *along* the *tangent*, and the *other towards* the *centre* of the circle. The latter in the case of a particle tied to the centre by a string (which prevents the particle from leaving the circle) is *supplied* by the *tension* of the *string* and, since action and reaction are equal and opposite, it follows that the *particle exerts a force upon* the *string acting away from the centre of the circle*. This action of particle upon the string or other means of constraint is frequently called the **centrifugal force**. It should always be borne in mind that it is the *reaction* of *the particle upon its means of constraint* (here string) *away from* the *centre of the circle* and *opposite* to the tension of the string, that is properly termed the **centrifugal**

force. This is *greater* the *greater* the *velocity* of the body and the *more* marked the *curvature* of the line along which the body passes. The *principle of centrifugal force* is *applied* in various *arts*. In sugar refineries it is used in removing syrups from crystals by placing them in a cylindrical vessel made of wire gauge which is then rapidly rotated. The centrifugal force throws away the syrup through the meshes of the gauge while the solid crystals are left behind. In glass factory also at first a small aperture is made in the hollow lump of the molten glass by blowing into it. After this it is rapidly rotated ; by the centrifugal force the aperture becomes larger and larger till ultimately the hollow globe opens out into a sheet. This principle is also applied in drying clothes in dye works and washing establisments It is owing to this force that the wheels of carriages are some times seen to be thrown off the rails when they move along curve. Dusts are also thrown off the carriage wheels by this force. In a circus riders and horses are seen to incline their bodies towards the centre to counteract this force.

QUESTIONS.

Q. 1. It is found that a cartesian diver when it is sunk *beyond* a *certain* depth, will not rise again, on removing the pressure ; but on tilting the jar on one side, it rises up and regains its original position. Explain this. (art 29.)

When the diver just floats in the water, its weight is equal to the weight of the water displaced by it. The *wt. of the diver* depends upon its *mass* ; and the *wt. of the displaced water*, depends upon *the total volume* of water displaced by the diver. Now the total volume of water displaced by the diver when it just floats is equal to the *volume of its mass plus the volume of the air inside the ball* ; since it is this air that prevents the water entering into the ball and thus displaces the water.

Now when the *bladder is pressed down*, the air in the cylinder is compressed ; this pressure is transmitted to the air in the ball, the *enclosed air is compressed*, consequently the *total volume of displaced water becomes less* than before *i.e.*, *the upward pressure is diminished*. But the weight (depending on the mass of the diver) remains the same as before, therefore *the figure sinks*.

As it sinks the *pressure on* the *air* inside the ball is *increased*, since when the figure was just floating the pressure on the air (before the bladder was pressed down) was one atmosphere. Now as it goes down the pressure on the enclosed air at any point (after the pressure on the bladder has been removed) will be *one atmosphere plus* the *pressure exerted by a column of water* whose height is equal *to the depth of the point*. Consequently the air inside the ball will remain compressed,even when the bladder is not pressed down ; therefore the total volume of the displaced water will be less than before ; the upward pressure being thus diminished, the figure will not rise again. But if on tilting the jar this *excess* of pressure on the enclosed air due to the column of water be diminished by decreasing the depth, so that the air inside the ball resumes its original volume, the figure will rise again.

Q. **2.** State what takes place if the *length* of the *outside arm* of a siphon is made (1) *equal to*, or (2) *less than*, the length of the *immersed arm above* the surface of water. What happens if a *hole* is made (1) in the *outside arm* at any point *below* the surface of water (2) any where in the tube *above* the free surface of water ?

(1) When the *length* of the outside arm is *equal* to the length of the immersed arm above the surface of water. The *upward pressure* at *the end* outside the vessel is *one atmosphere*, but the *downward pressure* of the liquid *at that end* due to the water in the tube is also one atmospere, since it is at the same level with the surface of water. Therefore the *water* will *remain at rest* in the *siphon*. *But when the length* of the outside is *less* than the other portion, the upward pressure at the end outside, which is one atmosphere as before, will be greater than the downward pressure of the liquid at that point ; for the latter is now *less* than one atmosphere, since it is higher than the free surface of water where the pressure is one atmosphere. Therefore the *water will be driven into the vessel* by the atmospheric pressure.

If *a hole is made* at any point *below* the free surface of water. The *upward pressure* at that point due to the air is *one atmosphere* but the *downward pressure* of water at the point is *greater* than one *atmosphere*,since it is *below* the free surface (where the pressure is one atmosphere). Therefore the water will flow out as before. But if *the hole* is made at any point *above the free surface* of water, the pressure of the atmosphere will be greater than the liquid pressure, the *air will enter into* the siphon and it will cease to work.

Q. 3. How is the period of oscillation of a pendulum affected (1) by the change of temperature, (2) by the height of a place from the sea-level ?

(1) We learn from the second law of pendulum that the period of oscillation of a pendulum varies as the square root of its length. Also it is known that heat expands bodies, therefore as the temperature *rises* the *length* of a pendulum *increases*. Hence the *period of oscillation increases with* the *rise of temperature.*

(2) We learn from the 4th law of pendulum that the time of an oscillation varies inversely as the square root of the force of gravity *i.e.* the time increases as the force of gravity diminishes. But we also know as we go farther and farther from the centre of the earth *i.e.*, as we ascend higher, the force of gravity diminishes. Hence

the period of oscillation increases, as the height of a place from the sea-level increases.

1. Define force ; how can it be measured ? Explain : velocity and acceleration. Enunciate "Parallelogram of forces" and show how that can be demonstrated experimentally. What do you understand by *composition* and resolution of forces.

2. Distinguish between gravitation and gravity. State the laws of gravitation and suggest any method by which they can be proved.

(3) Define *centre of gravity.* How is it determined experimentally in some cases ?

(4 Describe an ordinary balance, and state the conditions to be satisfied by a good and delicate balance.

(5) State and experimentally demonstrate the laws of falling bodies. What does the "guinea and feather experiment" prove ? Prove the second law by means of the inclined plane.

(6) State and verify the laws of pendulum.

(7) Define *centrifugal force.* Describe some phenomena that can be explained by this force.

HEAT.

1. In ordinary language we frequently use the same word to denote the *effect* produced as well as the *cause* which produces it ; so the word **heat** is used in **two** senses, (1) it means a *kind of sensation* ; (2) it is used as in this book to denote the *agent which produces the sensation.*

2. Theories—Two theories of heat have been advanced, viz, the *theory* of **emission** and that of **undulation.** The emission theory supposes that heat is caused by a subtle imponderable fluid which enters into a body and surrounds the molecules. It possesses a self-repulsive power and therefore acts in a contrary direction to the force of cohesion. It can also pass from one body to another. Under the undulation theory heat is not a *substance*, but a *condition* of matter, *i.e.*, a kind of oscillating motion of its molecules, which can be transferred from one body to another. This theory assumes that there is an imponderable ether pervading all matter and infinite space, which is capable of transmitting this vibratory motion. *Advantages of the second theory* are (1) it affords a better explanation of and discloses a close connection between heat and light ; (2) it explains phenomena which cannot be explained by the other theory.

3. The effects of heat—Expansion—Heat increases the temperature and volume of bodies, it alters their condition and decomposes them, and it also produces electricity. The principal physical **effects** produced by applying heat to a body are—(1)

change of volume (2) **change of temperature** (3) **change of state.** But as all bodies are surrounded by atmosphere which exerts a certain pressure on their surface on all sides, *in expansion* this pressure has to be overcome through a certain distance and a *portion of heat is thus expended in* doing this amount of *work.*

The repelling force of heat acts in a contrary direction to the force of cohesion. Therefore as the amount of heat in a body increases its intermolecular spaces are increased *i.e.*, molecules are thrown farther and farther apart and bodies *expand.* When this *force* of repulsion *balances* the molecular *attraction*, *bodies liquify ;* and when *it entirely overcomes cohesion they* are changed into *vapours.* In the gaseous state bodies are entirely without the sphere of mutual attraction.

In *solids* the molecules have a kind of vibratory motion about certain *fixed* positions. In the liquid state they have no fixed position, they rotate about their centres of gravity which move also. In the gaseous state the molecules are entirely free, they move in straight lines according to the ordinary laws of motion, until they encounter other molecules.

4. Expansion—As a general rule all bodies expand by the action of heat. Gases are the most expansible, liquids less so and solids the least.

Coefficient of expansion means the increase *of a unit volume, surface or length of a substance* when *the temperature is raised through one degree.*

As solids only have definite figures we may either consider their *expansion in one dimension* or the *linear* expansion ; in *two dimensions*, the *superficial* expansion, or in *three* dimensions, the *cubical* expansion.

The **Coefficient of linear expansion,** means the *increase* in length *of* a *unit length* of a substance when its temperature is raised through *one degree.*

The *coefficient of superficial expansion* is the amount of *increase* produced *in the unit* surface of a body by a rise of temperature through 1°. It is approximately equal to *twice* the *coeff.* of *linear expansion.*

Coefficient of cubical expansion is the increase produced in the unit volume of a body when the temperature rises through 1°. It is approximately equal to *three times that* of the *linear expansion.*

5. Linear expansion of solids-Expt—A rod is fixed at one end by a screw, while the other end presses against the short arm of a lever, whose long arm moves along a graduated scale. The point of the arm is at first at the zero point, but as the rod becomes heated, it expands and pushes the short arm. From the angle through which the pointer passes, the expansion of the rod can be determined. Rods of different metals indicate different angles, showing that their expansibility differs.

6. Cubical Expansion of solids-Expt—The *cubical expansion* of solids is shown by the *gravesand's ring*, which consists of a metallic ball which at the ordinary temperature *just* passes through the ring of almost the same diameter. But when the ball is heated, it no longer passes through the ring. This shows that it expands in volume by heat. *Different bodies possess different expansive powers* and it has been proved that the *coefficient of expansion of bodies increases with the temperature. Coefficients of expansion* also *vary* with the *physical condition of bodies*, being different for the same metal according as it is cast or hammered.

7. The coefficient of cubical expansion is three times that of linear expansion—To prove this, take a cube the length of whose side is 1 at 0°. Suppose L to be the coefficient of *linear* expansion, therefore in rising through one degree the side of the cube will be $1+L$, and its volume will be $(1+L)^3$, *or* $1+3L+3L^2+L^3$, but L being a very small fraction, its square and cube are neglected. Therefore the volume is $1+3L$ approximately, but the initial vol. was 1.$\therefore$ The increase is $3L$ *i.e. three times the linear expansion.*

8. Experiment—cubical expansion of liquids and gases—As *liquids* and *gases have no* definite *shapes we* can only *consider* their *cubical expansion* or that by volume. To show the *expansion of liquids*, a capillary tube with a bulb on its end is taken and filled with a coloured liquid up to a certain mark. When the heat is applied, the liquid rapidly rises. In order to show the *expansion of gases*, the tube with the bulb is filled with air and a thread of a coloured liquid is introduced into it to serve as an index, when heat is applied, the index is driven to the end of the tube, even for a small degree of heat.

9. Exceptions—It is seen then that heat generally expands bodies, but there is an important *exception* in the case of *iodide of silver*, which *contracts* when heated. *India-rubber* is another substance which *contracts on heating*. Also water between 0° and 4°. C forms another exception. The law of expansion by heat applies only to bodies which do not absorb moisture; those that absorb moisture are contracted when heated, because increase of temperature expels the moisture from their pores. As a general rule *bodies that expand by heat resume their original volume on cooling* to the former temperature, but certain metals especially *zinc* and *some kind of glass* form *exceptions.*

QUESTIONS.

Coefft of liniar expansion.

Let l_t be the length of the bar at t°.

lo ... ... 0°

Then $l_t - l_o$ = Expansion of l_o for t°

If the rate of expansion remains uniform from 0° to t°

$$\frac{l_t - l_o}{t} = \text{Expansion of } l_o \text{ for } 1^\circ$$

$$\frac{l_t - l_o}{l_o\ t} \quad \begin{array}{l}\text{Expansion of \textit{unit} length for } 1^\circ \\ = \text{Coefficient of linear expansion}\end{array}$$

If we denote it by α

$$\frac{l_t - l_o}{l_o\ t} = \alpha$$

$$l_t = l_o + l_o.\alpha.t.$$

$$= l_o(1+\alpha t)$$

Example. 1. An iron bar is 2.6 m long at 0°. What will be its length at 80c°, the coefft of expansion of iron = .0000122 ?

Here $l_t = 2.6\,(1 + .0000122 \times 80)$

$= 2.6 \times 1.000976 = 2.6025$

1. In what different senses the term *heat* is used ? (1)

2. Name the two principal theories of heat (2.) What are the advantages of the *undulatory theory* ? (2) State the theory (2)

3. Explain how heat expands bodies. (3) Describe experiments illustrating the *linear*, *superficial*, and *cubical* expansion of bodies. (5,6,8)

4. What are the principal effects of heat ? (3) Define : coefficient of expansion (4)

5. Define : coeff. of linear expansion and coeff. of cubical expansion. 4) Prove that the latter is *approximately* three times the former. (7)

6. Can you name any substance which contracts on heating ? Name two bodies which, after expansion by heat, do not regain their original volume on cooling. (9)

2. A steel metre scale is carefully measured at 10°C and its length is found to be 99·98 c.m. Find the temp. at which the scale is exactly 1 metre long ; coefft of Exp. = ·0000113.

3. An iron yard-measure is correct at the temperature of melting ice, express its error at 60°C.

THERMOMETRY.

1. Temperature of a body is its thermal condition with reference to its power of imparting *sensible* heat to other bodies or receiving it from them. *It* is a *quality* of the body and is *quite distinct* from the *quantity of heat.* A body may have a high temperature and at the same time possess a very small quantity of heat, for instance if a cup of water be taken from a bucketful, both will indicate the same temperature, yet the quantities of heat contained in them are different, for if these two masses be exposed to the same source of heat, they will require different lengths of time to raise them to the same point of temperature.

2. Thermometer—its principle—*Thermometers* are instruments for determining temperatures of bodies. For this purpose we must make use of the effects of heat on one of the physical properties of bodies, the most convenient, accurate and easy to observe of which is the expansive effect. Expansion of solids being too small, and that of gases too great, liquids are best suited for the construction of thermometers. *Mercury* and *alcohol* are the two *liquids* chiefly *employed* ; the latter is used because it does not solidify even at the lowest temperature produced, and the *former* because its *expansion* is *regular*, its *range of temperature* is very *great* ; (*i.e.*, boils at a very high temp. and solidifies at a comparatively low one) ; it *has low specific heat* and is easily obtained in the pure state. The mercurial thermometer s most extensively used.

3. Mercury Thermometer—its construction.—Mercury thermometer consists of a capillary tube of uniform bore throughout, at the end of which is a bulb. The bulb and a part of the stem are filled with mercury and a scale placed near or graduated on the stem to measure the expansion (and therefore the temperature.)

Selection of the tube.—For the purpose of constructing a thermometer, a *capillary tube* of *uniform bore* should be taken. In order to *determine whether the bore is uniform* or not, a small thread of mercury is introduced into it, and made to travel from one end to the other. If the length of the mercury thread remains the same throughout, the bore is uniform ; if not, the bore is not uniform and the tube should either be rejected, or if used should be *calibrated.* The object of *calibrating* the tube is to divide it up into parts of equal capacity.

The filling of the tube.—For this purpose fuse a funnel at the end of the tube, place a small quantity of mercury in it, hold the tube *obliquely* and heat the bulb gently. The expanded air partially escapes by the funnel and on cooling the remaining part of the air contracts and a portion of the mercury passes into the bulb. Heat the bulb again, now the vapour of mercury will drive all the air from the bulb and the tube. *Heat it* again to *drive a portion of the mercury and hermetically seal the open end before a blowpipe.* The thermometer should now be allowed to cool very slowly, and should be put aside for several days, before the fixed points are marked.

4. The determination of the two fixed points.—Before graduating any thermometer we must determine the two *fixed* points at the two exremities, and the two points that are universally adopted are the melting point of ice and the boiling point of water under the normal atmospheric pressure. For it has been found by experiments that ice always melts at practically the same temperature whatever be the intensity of heat and that distilled water under the same pressure and in a vessel of the same kind always boils at the same temperature.

The Zero or melting point.—To determine this the bulb and part of the tube is *vertically* placed within a vessel full of *powdered ice* and provided with a hole at the bottom to let out the water formed. The point where the mercury stands in this position is marked as the zero point of the scale.

The boiling point.—To determine this a metallic vessel partly filled with distilled water and provided with a long broad tube at the top is taken and the water heated to boiling. There are apertures on the side of the tube, so that the vapour formed passes freely through them and the pressure on the surface of the water remains the same (*i.e.*) one atmosphere. The thermometer is placed within the vessel through a cork placed at the opening on the top of the tube; care is taken not to dip the bulb into the water since the upper layer only is at the boiling point. The *bulb* therefore *should be placed just over the surface of water*, so that it remains entirely surrounded by the vapour, and the point where the mercury in the tube stands is marked as the boiling point. *It must be borne in mind* that *the boiling point should be determined first*, for the glass when exposed to a great heat does *not* regain its original volume when reduced to the former temperature; consequently if the *zero point* is marked *first*,it is *raised i.e.*, now at zero degree temperature the mercury stands below the point marked in the tube as zero. The readings of the thermometer therefore become *too low*. Again as by the pressure of the atmosphere the volume *is gradually diminished*, there is a constant tendency to *lower the zero* point *i.e.*, the mercury at zero stands above the zero point marked in the tube. The readings then become *too high*.

5. Calibration—Since in mercury thermometers temperature is determined by the expansion of the liquid the indications of the thermometer are correct only when the *division* of the scale *corresponds* to *equal expansion* of *mercury* in the tube ; therefore the *scale* must be *graduated* as to *indicate equal capacities* in the tube. If the tube be of uniform bore, the lengths of the division, indicating equal capacities should be equal. If the bore be not uniform, parts of equal capacity must be represented by unequal lengths. This process of dividing the tube into parts of equal capacity by unequal lengths is called *Calibration*.

6. Graduation—The two fixed points are taken as the two limits and the space between them is divided into parts of equal capacity. Each division is called **a degree**. *A degree* really or physically *represents the expansion of mercury in the tube*. The space between the fixed points has been differently divided by different persons. At present three scales exist. (1) **Reaumur's** scale, which divides the space into 80 equal parts ; (2) Celsius's or the **centigrade** scale, in which there are 100 equal divisions ; (3) **Fahrenheit's** scale which divides the space into 180 equal parts. But the latter marks his zero point not at the ordinary zero point (*i.e.*, the melting temperature of ice) but at the temperature produced by mixing equal weights of sal-ammoniac and snow. This point is below the zero point of the other scales by 32 degrees of his scale.

Degrees can be marked on a paper or glass scale attached to the thermometer, but it is better to mark the divisions on the stem of the thermometer itself. For this purpose the stem is first covered with a thin coating of wax, upon which the divisions and numbers are marked with needle-point so as to lay bare the glass ; after this the marks are etched or bitten into the glass with hydrofluoric acid.

A degree of the centigrade scale represents 100th part of the expansion of mercury in the tube from the melting to the boiling point of the thermometer.

7. **Conversion of scales.**—The relation between the three scales are—

$$\left.\begin{array}{c}(F-32) : C : R\\ 9 : 5 : 4\end{array}\right\} \therefore \begin{array}{l}C=(F-32)\frac{5}{9}\\ R=(F-32)\frac{4}{9}\\ F=\frac{9}{5}C+32 \text{ or } \frac{9}{4}R+32\end{array}$$

The rules may be stated thus :—

To change from F° to C° *subtract* 32 *and then* multiply the remainder by $\frac{5}{9}$

To change from C° to F° multiply by $\frac{9}{5}$ and *then add* 32

Examples. 1. Find the centigrade temperature corresponding to 86°F

$$(86-32)\,\tfrac{5}{9}=54\times\tfrac{5}{9}=30^{\circ}C\ ?$$

2. What is the Fahrenheit scale corresponding to $-10^{\circ}C$?

$$F=\tfrac{9}{5}C+32$$

$$\therefore\ F=-\tfrac{9}{5}\times 10+32=14^{\circ}F.$$

3. Determine the temperatures on the centigrade scale, corresponding to 32°F and -40° F respectively.

8. **Tests of a good thermometer.**—They are as follows :—(1) when its bulb and stem are immersed in melting ice the top of the mercury column should stand just at zero.

(2) When placed just over the surface of water boiling in an open metallic vessel, so that it remains surrounded by water-vapour (barometer indicating 760 m. m.) the mercury should stand at 100°C.

(3) When the instrument is inverted the mercury should fill the tube *i.e.*, come in contact with the other extremity of the tube and fall with a metallic click, proving thereby the complete absence of air,

9. The **special advantages** of **mercury** as a **thermometric fluid** are

(1) The **regularity** of its **expansion** between $-36^{\circ}C$ and 100°C *i.e.* its expansion within that range is proportional to the degree of temperature.

(2) The **long range** of **temperature** it commands *i.e.*, it remains in the liquid state between—38.5 to 357°

(3) Its good **conductivity** of **heat** *i.e.*, it readily takes up the temperature of the medium in which it is placed.

(4) Its **low thermal capacity** *i.e.*, it requires a very small amount of heat to raise its temperature.

(5) The **ease** with which it is **obtained** in the **pure state**.

(6) Its **opacity**. It is opaque so that we *can easily read the indication*. We are not required to colour the liquid as in the case of alcohol.

(7) Its **property of not wetting the glass tube** in which it is contained.

Advantages of the mercurial thermometer—

(1) Its form and size are convenient.

(2) Its indications can be easily read.

(3) The *readings give the temperature* directly *without* any *corrections for barometric height.*

(4) It can be made as sensitive and *delicate* as we please by *making* the *bore very fine* and the *bulb* comparatively *large.*

10. Limits to the employment of mercurial thermometer.—As mercury freezes at—38°.5 and boils at 357°, *mercurial* thermometers cannot be used for temperatures beyond these two points. For lower temperatures *alcohol* thermometers are used. For higher temperatures the instruments called *pyrometers* are employed. (This instrument is similar to the apparatus used to show the linear expansion of solids.)

But the expansion of mercury being *regular* between—36s and 100°C, for accurate observation mercurial thermometer° should be used within this range only.

11. General remarks.—*Errors and corrections.* In taking the temperature of a place or body accurately by means of a mercurial thermometer, the following corrections are necessary:—

(1). **The gradual lowering of the Zero-point.**—This is due to the slow contraction of the bulb (See art 4). So that the *readings are higher than the actual temperature.*

(2). **The temporary rise of the Zero-point.**—This occurs when the instrument has been exposed to a high temperature. This is due to the fact that when glass is exposed to a high temperature, it does not regain its original volume on cooling the bulb, therefore it does not contract at once to its normal size, so that the *readings* of the thermometer are *too low* for some hours.

(3). **Error due to exposure of the stem**—In determining the temperature of a liquid or vapour, the *bulb and the part of the stem containing mercury* should be immersed, for when the bulb is immersed, the mercury in the stem remains exposed to the air (whose temperature is different from that of the body). The whole of the mercury not being at the same temperature the *reading will be too low.*

(4). **Error due to position.**—A thermometer used in *a horizontal position* will give *higher* readings *than* when it is *vertical*, on account of the removal of the hydrostatic pressure due to the mercury column.

12. Leslie's differential thermometer—It is used to show the difference of temperature between two neighbouring bodies or places It consists of two bulbs of equal volume filled with air and connected together by a tube bent twice at right angles. A little coloured liquid fills the lower part of the tube and rises to the same level in the two legs of the tube when the bulbs are at the same temperature. But if one becomes warmer, the air in it expands and pushes down the column in this leg and raises that in the other. From the difference in the levels in the two legs difference of temperature can be calculated.

13. Applications of expansion of solids in arts—(1) Harrison's Gridiron pendulum.—We know that the length of a pendulum is affected by temperature. But as the time of oscillation of a pendulum depends upon its length, its period of oscillation will be affected by temperature, therefore the indication of a clock with an ordinary pendulum is not correct at all times. In order to remedy this defect, compensating pendulums have been constructed, the time of oscillation of which is not at all affected by temperature. **Gridiron pendulum invented by Harrison is one of them.**—It consists of a number of rods of two different metals, generally of iron and brass, disposed symmetrically on each side of the centre bar and connected together at top and bottom by cross pieces. They are so fixed that *one* pair can *expand upwards* while the *other* expands *downwards.* Their lengths are so adjusted that the expansion of the one is just counteracted by the expansion of the other, so that the position of the C. G. of the system is unaffected by changes of temperature. The expansion of the pair is exactly the same as that of a single bar; the other bar is used to give strength and symmetry to the system, it does not increase the expansion. Thus the *effective lengths* of the brass rods is the sum of the lengths of the rods on the left hand (or the right hand) side. The effective length of the iron rods is the sum of the lengths of the centre rod and of those on its left hand (or on its right hand). It is in *this sense* the word *length* has been used in what follows.

The *condition for* exact *compensation* in a gridiron pendulum is that the *lengths* of the two sets of bars must be *inversely proportional* to their *co-efficients of expansion.*

If l be the length at any temperature of the set of bars which expand downwards and l', the length at the same temperature of the set which expand upwards; let α and α' be their respective co-efficients of expansion. At any temperature t°, the downward expansion of the first set. $l.\alpha.$ t and the upward expansion of the second set is $l'.\alpha'$ t. Since C.G. of the system is not altered by changes of temperature

we must have $l.\alpha.\,t = l'\alpha'.t.$

$$l.\alpha = l'\alpha'.$$

C. U. **Question.**—Describe a gridiron pendulum made of copper and iron bars. What must be the relative lengths of the two metals?

Coeff. of lin. Exp. of copper ... ·000017
,, ,, ,, iron ... ·000011

If l and l' be the effective lengths of copper and iron respectively, then from the formula $l.\alpha = l'\cdot\alpha'$ we get $\frac{l}{l'} = \frac{11}{17}$.

(2), Spiral thermometer.—When two long strips of different metals, whose coefficients of expansion are different are firmly rivetted together and *heated*, the two metals expand differently; and on account of the unequal expansion the compound *strip bends*, the more expansible metal occupying the outer position. On the other hand, if the compound strip is *cooled* the more expansible will contract to a greater extent and the piece is *bent* again but in *the opposite* direction; in this case, the more expansible metal occupies *inner position*. Now if we keep one extremity of the strip fixed, owing to this bending of the piece, the *free extremity* of the piece will *move* in *one direction* or *the other*, according as it *is heated* or *cooled*. Hence from the direction of motion we can determine whether the body has been exposed to a higher or lower temperature. **Spiral thermometer** is constructed on this principle. It consists of a coil of two strips of steel and brass soldered together, the steel being placed uppermost. One end of the coil is fixed and the other is free and is placed between the two indicators, so that when the temperature falls it presses the one indicator in one direction, while the rise of temperature is indicated by the other being moved in the opposite direction. It therefore serves the purpose of a maximum and minimum thermometer.

N.B.—14. *Instances of precautions* taken to *avoid* the *effects of the expansion* of solids.

(1) Bars of furnaces are not fitted tightly at their extremities.

(2) In making railways a small space is left between successive rails.

(3) Water pipes are fitted to one another by telescopic joints, which allow room for expansion.

Application of the contractile force exerted on cooling.

(1) To secure tires on wheels, they are heated at first, then placed on the circumferences of the wheels and cooled.

(2) When the walls of the conservatory of arts began to bulge outwards, they were drawn in by passing iron bars across the building, and screwing them unto the plates outside the walls. When each alternate bar had expanded, it was screwed up. The bars, being then allowed to cool contracted, and in so doing drew the walls together.

QUESTIONS.

1. Define *temperature.* Show how it is distinct from the quantity of heat. (1)

2. Describe fully the construction and graduation of a thermometer (2) the process of filling it (3), the determination of the freezing (4) and the boiling points (4). Why is mercury chiefly employed in the construction ? (9)

3. Why is it that the boiling point should be determined before the freezing point ? (4)

4. What are the tests of a delicate thermometer ? (8)

5. What are the different scales that are chiefly used and what is the rule for the conversion of one scale into the other ? (7) What do you understand by 1°C. as measured by a mercurial thermometer ? (6)

6. Within what range of temperature can the mercurial thermometer be accurately employed ? (10)

7. What is the construction of an alcohol thermometer ?

8. Describe Leslie's differential thermometer, gridiron pendulum and spiral thermometer. (12. 13)

9. What are the advantages of a mercurial thermometer ? (9) What precautions are necessary in order to make an accurate observation with a mercury thermometer ? (11)

10. Two long strips of different metals are firmly rivetted together ; describe what will happen when they are heated, and mention any application of the fact observed. [13 (2)]

11. Give axamples in which practical advantage is taken of the contraction of metals on cooling, and other examples in which the effect of expansion due to heating has to be guarded against (14).

EXPANSION OF LIQUIDS.

1. **Real and apparent** Expansion.—Liquids are more expansible than solids, because in them the particles are less under the force of cohesion. Their expansibility is less regular, especially near the temperature of their boiling points. As liquid is always contained in a vessel, so it has two kinds of expansion, **real or absolute** *and* **apparent**. The *former* is the *actual increase in volume of the liquid when* its temperature is raised. But *when we heat the liquid* in a *vessel* the *latter* is heated with it and consequently expanded, so that *the increase in volume that we observe is not* its real but *apparent expansion* and is due to *the excess of its real expansion over that of the vessel.* As apparent expan-

sion is first determined by means of experiment, *if we add to it the expansion of the vessel* we get *real expansion* of the liquid.

In the case of solids this distinction is not necessary, for heat is applied to them *directly* (*i.e* they are not placed in any vessel when heated), so that the expansion that is observed is the absolute expansion. Again in the case of gases, this distinction is not made though they are always heated in a vessel, because the expansion of the vessel being *very small* compared with that of the gas, its apparent expansion is for all practical purposes very nearly equal to its absolute expansion.

Experiment—Take a tube having a bulb on one end and with a mark on the stem. Fill it with a coloured liquid up to the mark and heat the bulb. You will observe that the *column will sink at first* and *then rise again.* This shows that *heat expands the vessel first before heating the liquid*, but when the liquid is heated, it expands and its expansion being greater than that of the vessel, the column rises.

3. Different Liquids possess different expansive powers,and even for the same liquid the coefficient of expansion increases with the temperature.

4. The point of Maximum density of water—Hope's Expt.—To the general rule that bodies expand on heating and contract when cooled, **water** forms a remarkable exception **between 0°C and 4°C** *i. e.*, within this range it **contracts on heating** and **expands when cooled.** Above 4°C. it obeys the general rule. This has been proved by **Hope**. It can be shown in the following way; take a tall vessel filled with water above 4°C. Place two thermometers (one near the bottom and another near the top, cool the middle part by means of ice, the thermometer *below* will *indicate lower temperature first, then the two will be at* 4°C. after this the thermometer *above will* begin to *sink*; it will indicate 0°C while the lower one remains the same. It proves that *a quantity of water at* 4°C. *weighs more than at any other temperature*, and this is expressed by saying that **the point of maximum density of water is 4°C.** It is evident from the facts that if we raise water above that degree it expands and consequently becomes lighter and again if we lower it below 4°C. it will expand again. Therefore water *contracts to the greatest extent at 4° C.*

5. The importance of this peculiar behaviour of water in the economy of nature.—The fact that *water* *expands* on cooling from 4°c. to 0°c. is of great importance in nature. In winter the temperature of lakes and ponds falls, from being in contact with the cold air, and from other causes, such as radiation. As the water cools it becomes heavier and sinks to the bottom, its place being occupied by warmer and lighter water. This continual circulation stops when the temperature of the whole reaches 4°c ; after this the colder water being lighter floats on the surface and ultimately freezes. The sheet of ice thus formed on the surface protects the water from further cooling, since it is a bad conductor of heat. Thus the deep water of lakes in England seldom falls below 4°c, even in the most severe winters, so that fish and other aquatic animals are not destroyed.

QUESTIONS.

1. What do you understand by the "apparent expansion" of liquids ? Show how you can determine the *absolute expansion* from it (2). (*a*) When you heat a bulbed tube with water and apply heat at the bottom, the liquid at first sinks and then begins to rise. Explain this (2). (*b*) In determining experimentally the expansion of a liquid why is the distinction between absolute and apparent expansion necessary ? Why is it not made in the case of solids and gases ? (2)

2. Give the meaning of the expression *the point of maximum density of water* (4). Describe Hope's Experiment (4). What do you understand by the expression *the point of maximum density of water is 4°C.*

4. What peculiarity is observed in water when it is heated from 0° to 4° ? Point out its importance in the economy of nature. (5)

EXPANSION OF GASES.

1. Gases.—Gases are the most expansible of all bodies and their expansion is the most regular. It has been **proved by Gay Lussac that all gases have the same coefficient of expansion,** *i. e.*, they expand to the same extent for the same increase of temperature. But Regnault and others have proved that coefficients of several gases do present slight differences, but for all practical purposes they may be assumed to be the same.

2. Charles or Gay Lussac's law or the law relating to volume and temperature when pressure is constant.—Experiments made by Gay Lussac have established the following law :—

The volume of a given mass of gas, kept at a constant pressure, increases by a definite fraction of its volume at 0° for each degree rise in temperature.—This *fraction* is called the *coefficient of* expansion of the gas. *For all gases* the *value of the fraction* is the *same* and is about $\frac{1}{273}$ so that if we take a quantity of gas whose volume at 0° is V_0, its volume will be

$$V_0 + \frac{V_0}{273} \text{ at } 1^\circ$$

$$V_0 \times \frac{2V_0}{273} \text{ at } 2^\circ$$

$$V_0 + \frac{V_0 . t}{273} \text{ at } t^\circ$$

if we denote the volume at t° by V_t then

$$V_t = V_0\left(1 + \frac{t}{273}\right) \quad \ldots \quad (1)$$

If the symbol α is used to denote the coeff. of cubical expansion of gas then $\alpha = \frac{1}{273}$ and the equation (1) assumes the form

$$V_t = V_0 (1 + \alpha t) \quad \ldots \quad \ldots \quad (2)$$

Examples 1. What will be the volume 13 litres of air at 0°c. when the temperature is raised through 63°c.

$$V_t = V_0 (1 \times \alpha t)$$

Here $V_0 = 13$; $t = 63$ and $\alpha = \frac{1}{273}$

$$V_t = 13\left(1 + \frac{63}{273}\right)$$

$$= 13\left(1 + \frac{3}{13}\right) = 13 \times \frac{16}{13} = 16 \text{ litres.}$$

2. At what temperature will 3 litres of oxygen at 0°c occupy 5 litres?

3. A certain quantity of hydrogen gas occupies 11 litres at 156°c: find its volume at 0°c

4. A gas occupies 10·5 litres at 127°c. What will be its volume at 47°?

3. The law relating to volume and pressure at constant temperature or Boyle's law.—Gases obey another law, known as **Boyle or Mariotte's law.** It states that the **temperature remaining constant, the volume which a gas occupies is inversely proportional to the pressure to which it is subjected.** If v be the volume which the gas occupies under the pressure p, and v′ its volume under p′, then $v.p = v' p'$.

4. Density.—The relative density *of any substance expresses the ratio of the weight of a certain volume of the substance compared with that of the same volume of the standard body at the same temperature.* The weight of a unit volume of the standard substance is generally taken as *unity.* In case of solids and liquids water is taken as the standard, in case of gases the standard is air. But *as gases are compressible,* in order to determine their densities *we must reduce them to the same temperature and pressure.*

5. Applications.—The expansion and contraction of gases afford us numerous applications in nature as well as in domestic economy. They are the cause of all winds which carry the clouds formed above or near the seas, to the centres of lands where they condense and fall as rain and thus fertilise the soil, and give rise to numerous rivers. In domestic economy chimneys are used to produce a rapid current of air which supports and quickens combustion. This draught is due to the expansion of air.

QUESTIONS.

1. What is GayLussac's law for the expansion of gases? (2)Enumerate some of the applications of the expansion of gases (5).

2. Define *density*, and describe the experiment by which the densities of different gases have been determined (4).

3. What do you understand by the expression that the coefficient of expansion of air is $\frac{1}{273}$? What is there peculiar in the expansion of gases as compared with the expansion of solids and liquids? How do you prove it? (2)

CHANGE IN THE CONDITION OF BODIES BY HEAT.

Change of state.—It has already been stated that heat also produces a change in the physical state of bodies. This includes a change of a body (1) from solid to liquid, called *fusion* or melting; (2) from liquid to solid, called *solidification*, congelation or freezing, (3) from liquid to vapour, called *vaporisation*, (4) from vapour to liquid, called *condensation* or *liquefaction*, (5) from solid to vapour, called *volatilisation*, (6) from vapour to solid, called *sublimation.*

A. Fusion.

1. Fusion is the passage of the solid body to the liquid state by the action of heat.—This is produced when the repulsive force of heat balances cohesion which unites the molecules of a body. But as this cohesive force varies in different bodies, the temperature at which they melt varies accordingly. Some substances such as paper, wood, wool &c. do not fuse at a high temperature, but are decomposed.

Refractory bodies *are those that are supposed to be incapable of fusion,* such as carbon, lime &c. But there is no substance in this universe which can properly be called *refractory* because in proportion in which it has been made possible to produce high temperature, their number has been decreased.

Vitreous fusion.—*Some substances,* such as glass, iron, wax &c. *pass from solid to the liquid state without showing any definite melting point*; they pass imperceptibly from the solid to the liquid state. *They begin to melt at a certain* temperature and *fusion is complete at another temperature.* Within this range of temperature, the body remains in the intermediate condition, commonly known as the *plastic condition.* This sort of phenomenon is called *vitreous fusion.*

Melting point is the *definite temperature at which a body passes from the solid to the liquid state.*

2. Laws of fusion.—The following laws are observed by all *substances* that *do not decompose on melting.*

(*i*) *Each substance begins to fuse at a certain temperature, which is constant for the same substance if the pressure remains constant (ii) whatever be the intensity of the source of heat, from the time when fusion commences, the temperature of the body remains the same until the fusion is complete.*

Place a piece of ice in front of the fire, it will melt more rapidly but the temperature will remain the same until the whole of it is melted.

3. Influence of pressure on the melting point.—The atmosphere presses every body on all sides,so that if a body increases its volume on melting, it does a certain amount of work in overcoming the pressure of the air, and as this work depends upon the superincumbent pressure, if the pressure on the body be increased, greater amount of work must be done when the body melts and thereby expands. Now as this work is done at the expense of heat used in melting the body, greater amount of heat must be required to melt a body under greater pressure. Therefore *the law* which might be regarded as the **3rd law of fusion** *is that with an increase of pressure the melting point must be raised in case of substances that increase in volume on melting.* Conversely when a *body contracts on melting as* in the case of ice, the *increase* *of pressure lowers the melting point*, because the work is *assimilated* here in the form of heat as in the former case heat is converted into work.

4. Latent heat.—It means the *heat which is absorbed in changing the condition of bodies without the change of temperature.* It is called latent (hidden) because its presence cannot be detected by the thermometer. **The heat which is required to change the body from solid to liquid** is called the **latent heat of fusion** ; that *which is absorbed in passing from liquid to the gaseous state is called the latent heat of vaporisation.*

Latent heat of fusion of ice—*(or the latent heat of water)* is *the amount of heat required to change the unit mass of ice at 0° into water at the same temperature.*

Unit of heat.—The *thermal unit* or the unit of heat *means the quantity of heat required to raise a unit weight of the standard substance* (1 ℔ of water) *through unit degree of temperature.*

If 1 ℔ of *water at* 0° is *mixed* with 1 ℔ *of water at* 80°, the *resulting temperature* of the mixture *is* 40°. *i.e.* the 1st ℔ has been raised from 0° to 40° and the heat which it has absorbed has lowered the temperature of the *2nd* ℔ from 80 to 40° *i.e.*, through 40°. But if 1 ℔ *of ice* at 0° be *mixed* with 1 ℔ *of water at* 80°, the *resulting temperature* of the mixture *is found to be* 0°. This shows that 1 lb. of *ice at* 0° *has been converted into water at* 0° and the *heat* which it has *absorbed* to effect this change *has lowered the temperature of* 1 lb. *of water through* 80°. Thus we learn that to *convert* 1 lb. *of ice at* 0° *into water at* 0°, 80 *units of heat are required i.e.*, heat sufficient to raise 80 lbs of water through 1° or 1 lb. of water through 80°. This is expressed by saying that the **latent heat of fusion of ice is 80.**

$$\left.\begin{array}{l}\text{Heat contained in}\\ \text{1 lb. of water at 0°C}\end{array}\right\} = \left\{\begin{array}{l}\text{Heat contained in 1 lb. of ice}\\ \text{at 0°C + 80 thermal units.}\end{array}\right.$$

5. Physical explanation.—We know from experience that the temperature of a body remains constant until the fusion is complete, so that the heat applied in melting a body is taken up *internally*, and is used up in overcoming the cohesion of molecules. As the molecules of different bodies are attracted by different cohesive powers, so every substance in melting absorbs a different quantity of heat *i. e.*, every liquid has its own latent heat. This *heat is required to maintain the body in its altered state*, and if by any means you can take away this quantity of heat from the body, its condition will be changed (*i. e.*, if the body be now in the liquid state it will be converted into solid, If you *change* the *condition* of the body in the *reverse order* (*i. e.*, convert the liquid into a solid it will *give out this amount of heat.*

6. Solidification.—It is the passage of a body from the liquid to the solid state.

Laws of solidification—(*i.*) *Every body under the same pressure, solidifies at a fixed temperature which is the same as that of fusion.* (*ii*) *From the commencement to the end of solidification, the temperature of a liquid remains constant.*

Certain bodies, specially some of the fats, *present* an *exception to* the *first law* in so far that by repeated fusions they seem to undergo a molecular change which alters their melting point.

7. Expansion of water on solidification—Major William's expt.—*Water presents an exception to the general rule that solids occupy less volume* than the liquids from which they are produced, so that *when it solidifies its volume undergoes* a material *increase. The increase* of volume in the formation of ice is *accompanied by an expansive force.* This is seen in the bursting of water pipes in winter in cold countries. The splitting of rocks, stones and the swelling of moist ground are caused by the water penetrating into the pores and separating the parts when frozen. Major Williams in his Canada expedition burst bomb shells by filling them with water, plugging the holes, and placing them in frozen ice.

Cast-iron, bismuth and antimony *expand on solidifying*, like **water**, and can thus be used for casting.

QUESTIONS.

1. Explain *fusion*—What do you understand by a *refractory* body What is *vitreous fusion?* (1)
2. Establish (experimentally) the two laws of fusion. (2)
3. The increase of pressure raises the melting point in cases of bodies whose volumes are increased in melting. Explain this. (3)
4. When is heat said to become *latent?* Define *latent heat of fusions* (4) What do you understand by the expression that the latent heat of water is 80.
5. Define *Solidification*, and demonstrate its laws (6). What are *congelation* and sublimation ?
6. Why does ice float on water ? Describe Major William's experiment. (7) What does it prove ?
7. Enumerate the bodies that expand on solidification. (8)

B. FORMATION OF VAPOURS.

1. Vapour.—When sufficient heat is applied to a body,at a certain point it overcomes the cohesive force of molecules ; then the body assumes the gaseous state, unless it be of such a nature that it is decomposed before assuming this state. *Vapours* then *are* the *aeriform fluids into which substances are changed by heat.* Generally when a solid passes into the gaseous state it first assumes the intermediate state of a liquid. But sometimes *the passage of a solid into the gaseous state* is *completed without the intermediate form of liquid being* assumed. *This is called sublimation.*

Liquids are divided into *two classes* in respect to their property of disengaging vapours ; (1) **volatile liquids** are *those that have* a *tendency* to pass *into the state of vapour* at ordinary or even lower temperatures, as water, ether and the essential oils. (2) **Fixed liquids** are *those that emit no vapour at any temperature*, as fatty oils. When strongly heated they are decomposed, and do not emit vapours of the same nature as their own. There are some bodies, such as *drying oils*, that become thicker in the air ; this is not in consequence of evaporation but because they absorb oxygen from the air and undergo a chemical change. Vapours of the colourless liquids are generally colourless.

3. Vaporisation.—It is the *passage of the liquid into the gaseous state under all circumstances whether slow or rapid, in air or in a vacuum.* It is a general name for a process of which *there are two varieties*: (1) **Evaporation** which means the *slow production of vapour at the free surface of the liquid* at all temperatures : (2) **Ebullition** or boiling which *is the rapid production of vapour in the mass of the liquid itself at a certain temperature.*

4. Elastic force of vapours,—Like gases vapours have a certain elastic force, in virtue of which they are disengaged from the surface of a liquid, but this force at the ordinary temperature is much less than the atmospheric pressure and hence liquids exposed to the air evaporate very slowly. Owing to this force vapours exert pressures on the side of the vessels in which they are placed. **Tension** or **elastic force** of *the vapour* of a liquid *is the forcc which the vapour exerts on the sides of the vessel at any temperature.*

Experiment—To prove the elastic force of vapours, take a bent tube which has the shorter limb closed. The shorter limb and part of the longer one are filled with mercury, and a drop of any volatile liquid is introduced into the shorter leg. The liquid in consequence of its lower density will rise to the top. Dip the tube in a bath at a temperature higher than the boiling point of the liquid, *mercury* in the shorter leg *will sink*, thus *proving the elastic force of the vapour* formed. This *tension will increase with the temperature* and continue as long as any liquid remains to be vaporised. Crackling of woods in fire is due to the increased tension of vapours formed in the pores during combustion.

5. Formation of vapours in a vacuum.—*The vapour of every liquid has its own elastic force*, but the fact that the liquids, when exposed to the air, slowly change into vapours, is due to the obstacle which the pressure of the atmosphere presents to the elastic force. *If we take away* this *atmospheric pressure*, *the resistance is removed; elastic force* then *acts freely*, and *immediately the vapour is formed.* It can be *seen* easily *by introducing a drop of a volatile liquid into the Torricellian vacuum of a barometer*, it *will be instantaneously evaporated* and the *column of mercury will be depressed.*

This depression is due to the pressure exerted by the vapour. As the liquid is introduced drop by drop, the mercury falls lower and lower until a point is reached, after which the introduction of more liquid does not cause any further depression. The evaporation stops at that point and a little of the liquid is seen on the top of the mercury. Before this, the space above the mercury was only *partially saturated* with the vapour of the liquid (*i.e.* it contained *unsaturated* vapour). It is now *saturated* and the vapour exerts its maximum pressure at that temperature. If now the temperature be raised, the mercury will fall lower and lower, showing that the *maximum vapour pressure increases with the temperature.*

If the experiments be repeated with *different volatile liquids* the *depression* of mercury *will be different*, thus proving that at the same temperature the tension of the vapour is different *i.e.*, the vapour pressure of a liquid depends upon the nature of the liquid.

6. Laws for the formation of vapour.—*(i) In a vacuum all volatile liquids are instantaneously converted into vapours.*

(ii) At the same temperature the vapours of different liquids have different elastic forces.

7. *(a)* **Maximum Tension—Saturated Space**—For a given *temperature the quantity of vapour which can be formed in a given space is always limited.* When a *given space has acquired all the vapours which it can, it is said to be* **saturated**. As no new vapour can then be formed within the space, as long as the temperature remains constant, *the elastic force of the vapour cannot increase and the vapour is then said to possess* **maximum tension** *at that temperature.* For the same temperature the *quantity of vapour which saturates a given space is the same whether this is vacuous or contains air.* The difference being that in the first case the evaporation is instantaneous, while in the other case it takes place slowly. Again *for the same space*, whether it be vacuous or full of air, the *quantity of vapour* which *saturates* it *varies directly with the temperature.*

(b) **SATURATED AND UNSATURATED VAPOURS.**—Vapours exhibit two distinct conditions according as they are *saturated* or not. An **unsaturated vapour** is one whose condition with respect to pressure or density is altered when it is brought in contact with its own liquid *at the same temperature.* Such a vapour behaves much like a gas, it *obeys Boyle's law &c.*

A saturated vapour is one whose condition is not at all affected or altered when it is brought in contact with its own liquid. In nature *vapour in contact with an excess of its own liquid is* always *saturated.* The pressure exerted by such a vapour is called the *maximum vapour pressure of the liquid*, since it is the greatest pressure which can be exerted by the vapour of the liquid *at that temperature.* It differs entirely from a gas since, for a given temperature it can neither be compressed nor dilated, its elastic force and density remaining constant *i.e.* it *does not obey Boyle's law.*

The *pressure* exerted by the saturated vapour *is the same* when the vaporisation takes place *in air as* when it takes *in vacuo.* The pressure *does not depend upon the volume* occupied by the vapour; it *depends* only *upon* (1) the *nature of the liquid*, and (2) *the temperature.* It increases with the temperature, the higher the temperature, the greater the pressure.

Dew-point.—The *temperature at which the air is saturated with the aqueous vapour* it contains is called the dew-point.

8. Evaporation.—It denotes *the quiet production of vapour at the surface of a liquid. It goes on at all temperatures but in it there is no formation* of bubbles.

Molecules of bodies at all temperatures are in a state of agitation. In the liquid condition the force of molecular attraction being very little, some of these molecules, lying in the free surface of the liquid, during their oscillatory movement pass beyond the range of attraction and remain suspended in the space above. This process is commonly known as **evaporation.** From what is stated it is easily seen that this can take place at all temperatures. But as the *temperature rises* the violence of agitation being increased, *greater number* of molecules *pass into* the *region beyond*, consequently the *rate of evaporation increases.* Also as *the extent of the free surface* is *increased* larger number of molecules *are in a position to move freely*, therefore the rate of evaporation increases with the extent of the free surface.

The **causes which influence the rapidity of evaporation** are (1) the *temperature* (2) the *quantity of the same vapour present in the atmosphere ;* (3) the *renewal of the atmosphere and* (4) *the extent of the free surface of the liquid.*

(i) Increase of temperature accelerates the evaporation by increasing the elastic force of the vapours *i.e.*, the rapidity of evaporation varies directly with the temperature. Take two bottles of water at different temperatures and observe the quantity evaporated in each case.

(*ii*) It has been shown that the atmospheric pressure is an obstacle to the formation of vapour. So with the diminution of pressure vapour ought to be formed more abundantly *i. e., the rapidity of evaporation varies inversely with the pressure.* Take a beaker of water into the reciever of an air-pump, and pump the air out. As you take the air out, the pressure on the surface of the water in the beaker will be diminished. The water will begin to evaporate. The instrument which determines the rate of evaporation of water is called *evaporometer.*

(iii) It has been observed that no evaporation takes place in a space already saturated with the vapour of the same liquid,and it reaches its maximum in air completely freed from this vapour. It follows therefore that *the rapidity of evaporation* depends upon the quantity of vapour present *i.e.*, it *varies inversely as the quantity present.* Therefore *the renewal of the air*, (by removing the saturated air and placing dry air in its place) *accelerates evaporation.* Linen hung out to dry in the air does so far more rapidly in a windy than in a calm day.

(iv) The greater is the extent of the surface which a liquid

presents to the air, the more numerous are the points from which vapour is disengaged. Hence *the rate of evaporatoin varies directly with the extent of the surface exposed.* Water when placed in a *broad shallow* basin evaporates more rapidly than when the same quantity is placed in a deep *narrow* vessel.

9. Ebullition.—It is the *rapid production of elastic bubbles of vapour in the mass of the liquid itself at a definite temperature.* If heat is applied at the bottom of a vessel containing a liquid, when the elastic force of the vapour of the liquid at that part becomes greater than the pressure of the liquid, there bubbles are disengaged. But at first as they rise they come in contact with the particles of the liquid at a lower temperature and are condensed before reaching the surface with a peculiar noise which is observed *just before* the liquid begins to boil—This is called **singing.**

But when the temperature of the liquid is raised to a certain point, the *disengaged bubbles come to the surface of the liquid.* It is then said to **boil.**

The temperature at which a liquid boils is called its **boiling point.** It is different for different liquids.

Laws of ebullition *(i) The temperature of ebullition or the boiling point increases with the pressure.*

(ii) For a given pressure, boiling commences at a certain temperature, which varies in different liquids, but which for equal pressures is always the same in the same liquid.

(iii) Whatever be the intensity of the source of heat, *as soon as the boiling commences, the temperature of the liquid remains stationary till the boiling is complete.*

Causes which influence the boiling point—The *boiling point* of a liquid *depends,* (1) on the *nature of the substance dissolved in the liquid*; (2) on the *amount of pressure to which the liquid is subjected*; (3) *on the nature of the vessel* in which the liquid boils, and (4) on the *nature of the liquid itself.*

(i) When the liquid contains in the solution any *substance* which *is less volatile* than itself, *it boils at a temperature higher* than the boiling point of the pure liquid, and the ebullition *is* the *more retarded the greater the quantity* of such substances present in the solution.

(ii) The *liquid boils at a point where the elastic force of its vapour is equal to the pressure of the atmosphere to which the liquid is subjected.* From this it follows that if the pressure be increas-

ed or diminished the boiling point would be raised or lowered, so that the *boiling point varies directly with the pressure.*

(iii) Gay Lussac has observed that water in a glass vessel boils at a higher temperature than in a metallic vessel. This is due to some *physical affinity* (viz, adhesion) between water and glass ; so that *if there is any affinity between the liquid and the* substance of which the *vessel* is made, *it exercises great influence on the boiling point of the liquid.* It generally *raises* the boiling point.

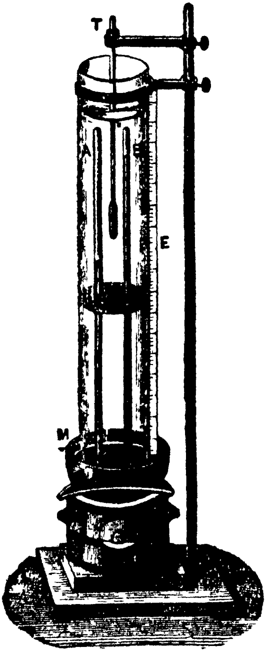
(iv) Some liquids, such as ether and sulphurous acid have very low boiling points, while others, such as mercury, have very high ones.

10. Boiling under diminished pressure—Hypsometer—Take a flask containing a little water with its mouth open and heat it. As soon as the air is expelled from it, so that it is full of water and vapour of water,stop the mouth by a well-fitting cork and plunge the flask in a vessel of cold water. The pressure on the liquid will be diminished by the condensation of the vapour by cold, but the temperature of the liquid remaining almost the same, the tension of the particles will become greater than the pressure above, and the boiling will commence again after the flask has been removed from the source of heat. Thus we see that a liquid may be made to boil at a lower temperature by diminishing the pressure.

It has been observed that as *we ascend higher* and higher, the *atmospheric pressure becomes less* and less still, and the water boils at a lower temperature, *so that at the top of a mountain water boils at a much lower temperature than at the sea-level.* Thus there is some *connection between* the *boiling point* (of a liquid) and *the height of a place* so that knowing the boiling point we can at once determine the height of a place. The instrument which has been invented for this purpose is called a **hypsometer.** It consists essentially of a little boiler. It terminates above into a telescopic tube into which is fitted a delicate thermometer. The thermometer dips into the steam and allows the boiling-point to be read. The boiling point of water at any any place is determined by this instrument. Then from the table of maximum tension of aqueous vapour, the tension corresponding to the boiling-point is determined. This is equal to the atmospheric pressure at that place. Now since the pressure is proportional to the height of a place, the height of the place from the sea-level is determined.

This law enables us to give **another definition** of boiling point—**The boiling point of a liquid is** *that temperature at which its vapour pressure is equal to the pressure of the atmosphere.*

11. Measurement of elastic force of aqueous vapour—Dalton has constructed an apparatus to measure the elastic force between 0°c and 100°c. In an oil bath at 0°c place two barometers; into the vacuum of one of these, introduce a small quantity of the liquid whose elastic force is to be determined. Then raise the temperature of the bath from 0°c to 100°c and mark the depression at each temperature, compared with the barometric height within the bath. As this depression is caused by the elastic force of the vapour at each temperature, we can easily calculate the elastic force from it. Dalton determined the elastic force of aqueous vapour in this manner.



12. Latent heat of vapour—It has been observed that whatever be the intensity of the source of heat the boiling point of a liquid under ordinary atmospheric pressure remains constant. It cannot be heated beyond that point, the pressure remaining constant. The more intense heat serves only to increase the rapidity of vaporisation. Hence all the heat which passes from the source to the liquid, is taken up by the vapour disengaged. But as the temperature of the vapour remains constant, it follows that the *heat is absorbed to change the substance from the liquid to the gaseous state* and is *required to maintain the body in its present gaseous state.*

Latent heat of vaporisation—It means the *quantity of heat necessary to convert the unit mass of a body from the liquid to the gaseous state without any alteration of temperature.*

Latent heat of vaporisation of water is 536—By this we mean that the quantity of heat necessary to convert 1℔ of water at 100°c into steam at the same temperature is 536 thermal units *i.e.*, it can raise 536℔s of water from 0° to 1°c.

$$\text{Thus }\left.\begin{array}{l}\text{Heat contained in}\\ \text{1℔ of steam at 100°c}\end{array}\right\}=\left\{\begin{array}{l}\text{Heat contained in 1℔ of water}\\ \text{at 100°c} + 536 \text{ thermal units.}\end{array}\right.$$

C. U. Question.—If the latent heat of fusion be represented by 79·25, and the latent heat of vaporisation by 536 units of heat, compare the heat necessary to raise 1 ℔ of water from 0°C to 100°C, with that required to convert 1 ℔ of ice at 0°C into steam at 100°C.

From the definition of thermal unit 1 ℔ of water in rising from 0°C to 100°C requires 100 units of heat.

To convert itself into water at 0°C. 1 ℔ of ice at 0° requires 79·25 units of heat.

1 ℔ of water in rising from 0° to 100°C requires 100 units of heat.

To convert itself into steam at 100°c. 1 ℔ of water at 100°C requires 536 units.

Hence the total quantity of heat required to convert 1 ℔ of ice at 0°C into steam at 100°C is 79·25 + 100 + 536 = 715·25

∴ The ratio of the latter to the former ... $\frac{715\cdot25}{100} = 7\cdot1525$

13. Cold due to evaporation.—*Liquids* are *vaporised either by heat* or *by diminution of pressure to* which they are subjected. In the *second method*, they do not receive any heat from any source, *they are simply placed under the receiver of an air-pump* to reduce the pressure and thereby to evaporate the liquid. Now whatever be the temperature whenever any vapour is produced from any liquid an absorption of heat always takes place, and in the present case (of evaporation by diminution of pressure) it will take up the heat from the liquid itself and thus lower its temperature. The *more is the evaporation the greater the cooling.* In this manner *cold may be artificially produced by the evaporation of volatile liquids*, such as ether, carbon disulphide etc., i. *e.*, by pouring them on the surface of a body and placing the body in a draught. From this it is evident that *the cooling effect* produced by a *wind is* not *due to* its cold temperature, (it may be warmer), but to *the rapid evaporation it causes* from the surface of the skin. In a hot country water is cooled by placing it in a porous earthen-pot, so that it percolates through the pores and is evaporated on the other side. In *every case of cold produced in this way there must be some evaporation.* Thus the cooling produced by the punkah and the freshness caused by watering the streets are due to evaporation.

Water and mercury may be frozen in a vacuum.—Leslie has frozen water by placing a thin shallow dish of water over a vessel containing sulphuric acid (a substance which absorbs aqueous vapours). The whole of it was then placed under the receiver of an air-pump and the air pumped out. The water then began to boil and as the sulphuric acid absorbed all the vapours as soon as they were formed, boiling went on rapidly and the temperature sank till the water was frozen into ice. Thelorier has produced a cold of —100°C by means of liquid carbonic acid. Despretz reduced alcohol to viscous state by the mixture of solid carbonic acid, ether and protoxide of nitrogen.

QUESTIONS.

1. What do you understand by *volatile* and *fixed* liquids ? (2) what is " Elastic force of vapours "? (4.) Describe the experiment by which it has been determined. (4)

2. Enumerate the laws for the formation of vapours and briefly describe the experiment by which they have been established (6,)

3. What is the meaning of the expression "Maximum tension of aqueous vapours ?" When a *space* is said to be *saturated* ? (7) Distinguish between *saturated* and *unsaturated* vapours. (7)

4. What is *Evaporation* ? How does it differ from ebullition ? (3). Mention the causes which accelerate the former (8). Explain the construction of *evaporometer*. Water placed in a broad shallow vessel evaporates more rapidly than in a deep narrow vessel. Explain this.

5. Establish the laws of Ebullition and mention the causes which influence the boling point of a liquid. (9)

6. How did Dalton first measure the elasticity of aqueous vapours ? Describe the apparatus (11).

7. Show how you can determine height from the boiling point of a liquid. What is a *hypsometer* ? (10)

8. What is latent heat of vapour ? Explain " the production of cold by evaporation." (12)

9. How can ice be prepared by means of an air-pump ? (12)

CALORIMETRY.

A thermal unit means the *quantity of heat necessary to raise one pound of water through* 1°*c*. In France the word *calorie* means the quantity of heat which raises one kilogramme of water through 1°c. (1. calorie = 2·2 thermal units).

The thermal capacity of *a body is always measured by the amount of heat required to raise its temperature through one degree.*

3. Specific heat of any body denotes the number *which expresses the ratio of the quantity of heat necessary to raise a unit mass of the substance through one degree of temperature compared with the heat necessary to raise the same mass of the standard sub-*

stance through one degree. i.e., an equal mass of water through the same interval of temperature.

TRANSMISSION OF HEAT.

1. Modes of transmission of heat—There are **three** processes or **modes** of transmission of heat from one point to another :—

1. **Radiation.** 2. **Conduction.** 3. **Convection.**

Radiation is the *passage* or *transference of heat from one point to another in straight lines* (in a homogeneous medium) *and without affecting the medium through which it passes.* It is by this process that the sun warms our earth.

Conduction is the *transmission of heat from hotter to colder parts of a body or from a hot to a cold body in contact with it, without any visible motion of the parts of the body.* When one end of a metallic rod is heated it is by this process that the other end gets heated after a certain time. *Through solid bodies heat is transmitted by this process.*

Convection is *the transmission of heat from hotter to colder parts of a body by actual motion of the parts of the body. This mode* of transmission *is possible* only *in liquids* and *gases* in which particles can move about very easily.

2. Chief points of distinction between the three modes of transmission.

Radiation.—(1) *It is a rapid process.* In the eclipse of the sun, it is found that the light and heat are cut off at the same time, hence both must travel with the same speed.

(2) It takes place *without affecting the intervening medium.*

(3) It takes place *in all directions.*

(4) It takes place *in straight lines* in a homogeneous medium.

(5) In it *the body* which receives heat is *at a distance from the source of heat i.e.* it is *not* in actual *contact* with it.

Conduction—(1) *It is a* gradual and *slow process.* (2) In this heat passes from hot to cold parts of a body by *heating the intermediate particles*, so that throughout its passage heat flows from the hot particle to the cold one. (3) In it the body which receives heat is in *actual contact* with the source of heat. (4) This process *is not restricted to straight lines*, for a bent wire conducts heat as well as a straight one. By means of these it can be distinguished from the 1st mode. (5) In this *there is no visible motion of the parts or particles of the body.* This distinguishes it from convection.

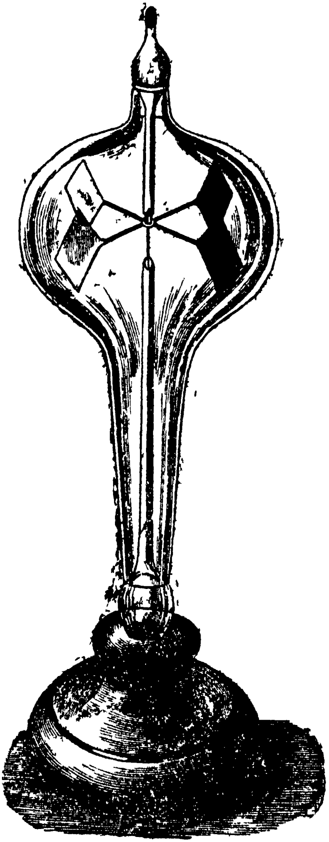
Convection—(1) This is *also a slow process.* (2) In this *the transmission* of heat always *takes place in one direction i.e.,* in the upward direction from the point heated. These distinguish it from radiation. (3) It takes place by *the actual motion of the particles heated.*

RADIATION.

1. **Explanation**—*Radiation* means the passage of heat from one body to another at a distance without affecting the medium through which the heat passes. The heat which is thus transmitted is called **radiant heat**. *Undulatory theory* assumes that the molecules of bodies are always in a state of vibration and that all space is pervaded by ether. In *radiation* these molecular *vibrations* of bodies are *communicated* to *the ether molecules* in contact with them, they transmit these motions to the next ether molecules and so on, these vibrations are carried to a distance, where they reach another body and increase the number of vibrations of its molecules (*i.e.* increase its temperature). As the vibrations transmitted through the ether are transmitted very quickly *they do not affect the* (perceptible) *medium air.* Also for the same reason *radiation may take place in a vacuum* (*i.e.*, in a place void of air but still pervaded by ether). Again *these vibrations are transmitted in every direction.* Therefore *all bodies* must *radiate heat in all directions.* Also the *molecules of all bodies are always in a state of vibration* whatever be its temperature, it follows from this *that bodies more or less* radiate heat *at all temperatures.* But *hot bodies, i.e.* those whose *number of molecular vibrations are greater, radiate more,*because they *transmit greater number of vibrations than cold ones.*

2. **These things** have been *verified* by *experiments* and the three *laws of radiation* are—

(I) *Radiation takes place in all directions round a body.* (II) *Radiant Heat is propagated in a right line in the same medium.* (III) *It is propagated in a vacuum as well as in the air.* The **first law** can be proved by placing very delicate thermometers on different sides of a hot sphere, at equal distances from the centre ; they will always give the same indications. **2nd law :** If a screen be placed in a right line which joins the source of heat and the thermometer, so as to cut off the **rays**, the latter is not affected. **3rd law :** To prove this a thermometer is fitted into a glass flask in such a manner that its bulb occupies the centre of the flask. The air is then pumped out of the flask and the neck hermetically sealed. On immersing this in hot water, the thermometer will be seen to rise. *This can also be proved* by a **radiometer.** In which there is a light vane placed on a pivot inside a vacuous glass vessel. The vane consists of four arms of aluminium wire, that are fixed at one end to a small cap placed on the pivot, while at the other ends are fixed small mica discs coated on one side with lampblack. As soon as a hot body is brought near it, the vane begins to rotate about the vertical axis. As the vessel is exhausted of air, it shows that heat is radiated through a vacuum.



3. Causes which modify the **intensity** of **radiant heat.**—The **intensity of radiant** *heat* means *the quantity of heat rays that fall on a unit area.*

(*i*) **The intensity of radiant heat is directly proportional to the temperature of the source of heat.** This is proved by placing bodies of 10°, 20° and 30° successively at equal distances from the thermometer and noticing the proportional rise of the temperature.

(*ii*) **The intensity of radiant heat is inversely as the**

square of the distance. To prove this a hot body is placed at the centre of two concentric spheres. It is evident that the quantity radiated is the same in both these cases, because the spheres surround the body and *all* the heat rays fall on the surfaces of the spheres. If i and i' be the intensities ; S and R ; s and r be the surfaces and radii of the spheres respectively and Q the quantity radiated in each case.

Then $i = \frac{Q}{S}$; $i' = \frac{Q}{s}$ $\therefore \frac{i}{i'} = \frac{s}{S} = \frac{4\pi r^2}{4\pi R^2}$ (because surfaces of spheres very directly as the squares of their radii). $\therefore \frac{i}{i'} = \frac{r^2}{R^2}$

As R and r are the distances of the surfaces from the hot body, it proves the second law.

(*iii*) *The intensity of oblique rays is proportional to the cosine of the angle which these rays form with the normal to the surface on which they fall.*

This is called the **law of cosine.**

4. Mobile Equilibrium of temperature—It follows from the theory of heat that, since heat is always present in a body whatever be its temperature. **Bodies** must **radiate heat at all temperatures,** therefore a *cold body must radiate heat* to spaces like a hot body. Also **since the quantity of heat radiated increases with the temperature,** a hot body will *radiate more heat* than a cold one. Therefore *when a cold body is placed near a hot one*, the cold body will radiate heat to the hot one, and the hot body will do the same towards the cold one. But the *hot* body will *give out more heat* to the cold body *than it receives* from the latter, whereas the cold body *will receive more heat* from the hot body *than it gives out.* The *effect* will be that the *temperature* of the *hot body* will be *lowered* and the *temperature of the cold body raised.* This goes on till *the bodies are brought to the same temperature.* After this *no change is observed* in the temperature of bodies. But even *at this stage radiation does not cease.* The reason why the bodies remain at the same temperature is, that at this stage, each *one receives as much heat as it gives out,* so that the total quantity of heat remains the same. **This state is therefore called the state of mobile equilibrium of temperature.**

Prevost's theory of exchange. This theory assumes *that bodies at all temperatures* are *constantly radiating heat towards spaces*, and that the quantity of *heat radiating from a body depends upon its own temperature* and on the nature and extent of its surface, *independent of the temperature of the surrounding medium.* The phenomena of radiation have been explained by this theory. From this it is evident that *in this universe all bodies tend to assume a uniform temperature* and that there is a necessary limit to the cooling of bodies.

CONDUCTION AND CONVECTION.

1. **Conduction** is the *propagation of heat through the mass of a body from molecule to molecule. In conduction heat must, throughout its passage, proceed from hotter particles to colder ones* (*i.e.* it must affect the particle through which it passes.) But *in radiation heat is transmitted* from one body to another at a distance *without affecting or raising* the temperature of *the medium through which it passes. Good conductors* are bodies which *readily* transmit heat through their mass, whereas *bad conductors* do this *with* very *great difficulty. Organic bodies conduct heat very badly ;* woods conduct better in the direction of the fibres than in a transverse direction ; glass, stone, leather, cotton, wool, straw and sawdust are all bad conductors.

2. **Solids** differ from one another enormously in their power of conducting heat. Metals are generally good conductors, silver and copper being the best.

3. **Ingenhaus' apparatus** to determine the relative conductivity of solids.—It consists of a metal trough with a number of tubulures into which are fixed rods of the same dimensions but of different metals. These rods extend to a slight distance within the trough and the parts outside are coated with wax. The trough being filled with boiling water, it is observed that the wax melt to a certain distance on the rods. The conducting power is assumed to be greater in proportion as the wax has fused to a greater distance. *This is not quite true*, for the *quantity of wax melted depends on the temperature of the body*, which *again varies with different bodies according to their specific heats.*

Tyndall has proved this by taking two precisely similar prisms one of bismuth and the other of iron, and coating the ends of each with white wax. He then placed them with their coated ends upwards on the lid of a hot vessel. The *wax on the bismuth* was observed to *melt first* *although iron* possesses *better conducting power*. The reason is, it requires more heat to raise bismuth to the melting point of wax. So also if you take two bars of different metals, but of the same conductivity, shape, surface and coating, after a few minutes you will see them melting the coating differently, because they will be at different temperatures ; although if you allow a sufficiently long time to elapse, the distribution will be the same in both the bars.

4. Liquids with the exception of mercury, which is a metal, are all bad conductors. To prove this take a test tube partly filled with water, and heat it near the surface of the water, it may boil at that place but you will perceive no heat at the bottom. In solid conductors wherever the heat may be applied it is transmitted in all directions and the whole mass becomes hot. *As liquids possess very little conducting power* you cannot heat the whole mass of any liquid *by applying heat* (at any part) *wherever you like* as in the case of solids. But as the particles of liquids are mobile, and are found to expand on the application of heat and thereby become lighter, if the heat be applied to the bottom of a vessel containing any liquid, the whole mass may be heated. Since the layer at the bottom gets heated first, be comes lighter than other layers, and consequently begins to rise upward. Its place is then occupied by another cold layer, which again is heated and ascends towards the surface and so on. Again these successive hot layers in their ascent come in contact with the cold particles, gradually become cold and after a time begin to sink. They come to the bottom again and being heated there again ascend upwards. So ascending and descending currents are set up throughout the whole mass and in this manner the liquid gets heated. This manner of transmission of heat by the motion of hot particles to the cold regions is called **convection.** It differs from conduction in the fact that whereas in convection there is a motion of hot particles to the cold region, in conduction there is no such motion, although in the former heat is ultimately transmitted by the little conducting power which the body possesses. **Convection** then depends upon the **three properties of bodies (1) expansions of particles by heat (2) mobility of particles (3) conductivity.**

Gases are extremely bad conductors. They are worse conductors than liquids, so they also transmit heat by convection. Conducting powers of liquids and gases have been determined by series of experiments by Guthrie.

QUESTIONS.

1. Describe the three methods by which heat is conveyed from one place to another, and distinguish convection from radiation. (1,2)
2. Define Radiant heat and Radiation. Explain the latter by the undulatory theory. (1)
3. What are the laws of radiation and how have they been (*a*) proved by experiments (2), (*b*) explained by the theory. (1)
4. What do you understand by "the intensity of radiant heat ?" What are the causes which modify it and how have they been experimentally established ? (3)
5. What is Prevost's theory of exchange ? What do you understand by "the mobile equilibrium of temperature" ? (4)
6. Define 'conduction' and 'conductivity' of bodies (1) Distinguish conduction from convection (4) On what property does convection depend ? (4)
7. Describe the experiments by which the conducting powers of (*a*) solid bodies (3), (*b*) of liquids have been determined. (3)
8. Mention some of the applications of the properties of conduction and convection in arts and manufactures.
9. Explain 'Trade winds' by convection of gases.

REFLECTION OF HEAT.

1. **Distribution of heat**—When heat rays from any source fall upon the surface of a body, *one portion enters into the body* and the *other is thrown back from the surface.* The *rays* that *enter into* the body *are divided into two* parts again :—1st is **transmitted** *i.e.*, it passes through the body without affecting the temperature of the body ; the 2nd is **absorbed** by the body, these rays go to increase the temperature of the body. Of the *rays* that *are thrown back* some are *driven off regularly in a definite direction* and are called **reflected** rays ; others are *irregularly thrown back in all* directions and are said to be **diffused**. Thus if the *quantity of heat* falling on a body be denoted *by I*, the quantity *reflected by R*, that *diffused*, by *D*, that *absorbed*, by A and that *transmitted*, by *T*. We have

$$I = R + D + A + T.$$

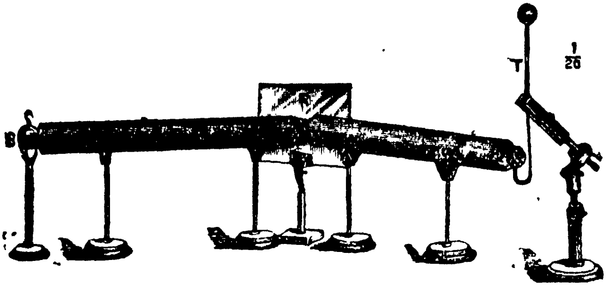
2. **Definition**—The *rays which fall on the reflecting surface are called incident* **rays** ; the *direction in which they fall is called the* **line of incidence** ; *the angle which incident ray at the point of incidence (i.e.,* where it meets the surface*) makes with the line perpendicular to the reflecting surface is called the* **angle of incidence**. The **angle of reflection** *is the angle which the reflected rays make with the normal.*

3. Laws of reflection, (i) *The angle of reflection is equal to the angle of incidence.*

(ii) The incident and the reflected ray must be in the same plane with the line perpendicular to the reflecting surface.

To **prove these** take a cubical metallic box filled with hot water and place before it a screen with a small hole in it to allow a certain number of rays to fall on the mirror, placed behind the screen. The incident rays are in the direction of the line joining the centre of the hole with middle point of the front face. If you measure the angle of incidence, and place the thermometer in the opposite direction in a line making an equal angle with it, you will see the thermometer rise. In any other direction it will not indicate any thing perceptible. You will also find that all these are in the plane pendicular to that of the mirror.

Another proof—Take two polished tin tubes and place them horizontally on stands, the two tubes making an angle of about 120° with one another. At the mouth of the one place one bulb of the differential thermometer and at the mouth of the other place the source of heat, either a redhot ball or a Leslie's cube. No effect will be produced on the thermometer. Now place a vertical sheet of bright tin plate *equally inclined to the two* tubes, the thermometer will be affected. If the position of the tin plate be *altered* it will be seen that the thermometer will be affected *very little*, but the heating effect is *greatest* when the reflector is *equally inclined to the two* tubes.



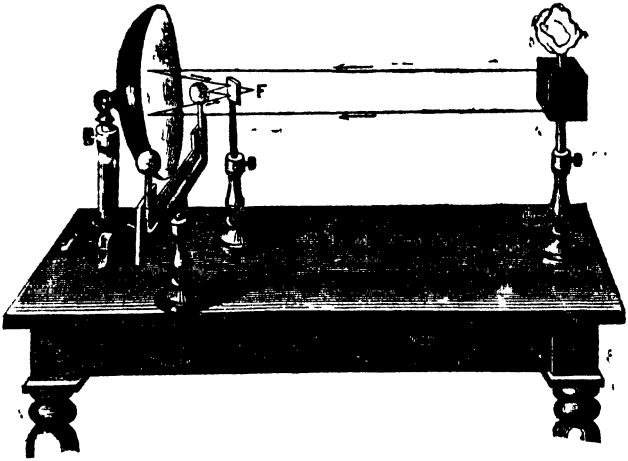
4. Concave mirrors are *curved reflecting surfaces;* they may be spheroidal or parabolic, and they are regarded as being made up of an infinite number of extremely small planes inclined towards each other, in such a manner as to determine the curvature. The curved surface is made up of the intersections of all the tangent planes drawn from every point on the surface. In *order to determine the angle of reflection* of a ray of light falling on any point of the spherical mirror, draw *a line from this point to the centre of the sphere* of which the mirror is a part. This line *will be perpendicular to the tangent plane at that point* and the *direction of the reflected ray will be along the line making an equal angle with the radius on the other side.* From the symmetrical arrangements of these small faces, it follows that when rays fall upon a concave mirror, they in obedience to the laws of reflection, meet at a point which is called the *focus.* The effects of heat become very powerful when it is reflected from the surface of concave mirrors which are some times therefore called *burning* mirrors (vide optics, concave mirrors).

5. Reflecting, absorbing and emissive powers of bodies. It has been . observed that heat rays falling on the surface of bodies are partly absorbed and partly reflected; the quantities of heat thus absorbed or reflected vary with different bodies; one set *reflects much* and absorbs little, and is therefore said to possess *reflecting* power; another set which *absorbs* a great deal of these rays is, for this reason, spoken of as possessing *absorbing* power.

The *relation between* the *absorbing* and *reflecting powers* may be seen from the equation already given $I = R + D + A + T$. Some bodies do not transmit heat at all so that T is zero and the quantity diffused D being very small may be neglected. Therefore the equation ultimately becomes $I = R + A$. This shows that where R is greatest A is least *i.e.*, **those that reflect best absorb least** and conversely **best absorbents are the worst reflectors.**

Emissive or radiating power of a body *is the property which it possesses of sending out* (emitting *more or less easily the heat which it contains.* It has been proved by experiments that **good absorbents are good radiators** and that for each substance *radiating power is* in all cases *directly proportional to its absorbing power.* By means of the same apparatus the reflecting, absorbing and emissive powers of bodies, can be compared by slightly altering the arrangement.

6. To determine the comparative reflecting powers of bodies.—Take a metallic cube filled with hot water, place a concave reflector in front of it and *keep the body, whose reflecting power is to be determined, between the mirror and its focus,* so that the reflected rays of the mirror may *fall on this body before being concentrated to the focus ;* and as the quantity of the rays that are reflected from the surface of this body, is to be measured, the differential *thermometer is placed at the point where the rays* reflected from the surface of the body *meet together.*



7. To determine the absorbing powers of bodies, *their thin films are* taken and *placed on one of the bulbs* of the differential *thermometer.* This *bulb* is then *placed at the focus of the* concave *mirror* in front of the hot body. The temperature indicated by the thermometer will determine the quantity absorbed in each case. But **emissive powers of bodies are determined** by placing their *thin films on the surface of the cube filled with hot water (i.e. the source of heat)*; because in that case only those rays that are *emitted* by the substance which covers the source of heat can be measured by placing the thermometer at the focus of the mirror. And from the indication of the thermometer in each case you can determine the quantity emitted.

By means of these methods you can determine the *comparative* powers only and not the *absolute* powers.

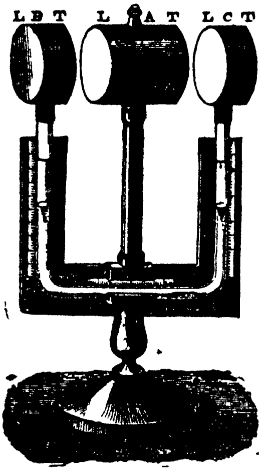
8. Causes which modify the reflecting, absorbing and radiating powers. It has been observed that bodies radiate as much heat as they absorb (*i.e.* the *radiating power increases with its absorbing power*, and also *that when cold, they absorb the same rays which they give out when hot*, therefore whatever affects the one power, affects the other in the same proportion. Again the *increase in the absorbing power causes diminution in the reflecting power of a body in such a way that their sum always remains constant* (see art 5).

(*a*) The *reflecting power of bodies increases with the degree of polish of the surface. Melloni also proved that it increases with the density.*

He observed that in case of hammered plates *scratching* diminished the reflecting power whereas in other plates the power was increased by it. He explained the phenomena by saying that in case of hammered plates the surface layer is always denser than the layer below ; and scratching exposes the less dense surface and thereby diminishes the reflecting power. But in ordinary plates scratching increases the density of the exposed surface by pressing the particles more closely together and as it also increases the reflecting power in this case, it is clear that the reflecting power depends upon the density.

(*b.*) *The absorbing power of bodies varies with the inclination of the incident rays. It is greatest when the rays are perpendicular to the surface and diminishes* in proportion *as the angle of incidence increases* (*i.e.* when the incident angle is greater, more rays are reflected and less absorbed). *It is also influenced by the nature of the source of heat i.e.* a body absorbs different quantities of heat from different sources. Thus, for the same quantity of heat, a surface coated with white lead, absorbs twice as much heat from a cube filled with hot water, as it does from an ordinary lamp.

(*c*) The *radiating power of a gaseous body in a state of combustion is very weak.* The temperature of hydrogen flame is very high but a thermometer placed near it indicates no change ; this proves that the flame has no radiating power. In the ordinary flame the radiation indicated is due to the solid particles present in the flame. The *radiating power of gases increases with their densities.*



9. The equality of absorbing and radiating powers of bodies has been proved by **Ritchie** by means of the apparatus constructed by him, which is based on the principle of the differential thermometer. In it instead of the two bulbs of the thermometer, two cylindrical canisters are used, having the same volume and section. One face of the canisters is covered with lamp black and the other face with tin foil. In the middle another similar canister of the *same sectional area*, and filled with hot water is placed as the source of heat. The canisters are so placed that the left face of each is covered with lampblack and the right face with tin. In the case of the differential thermometer it has been observed that if the two bulbs receive equal quantities of heat (*i e.* if they are raised to the same temperature), the liquid in the two legs remains on the same level, since the air in the two bulbs expands equally by heat. In this experiment it is found that after filling the middle canister with hot water, the liquid in the two legs remains in the same level. It proves that the canister on each side is receiving the same amount of heat. But as a large quantity of heat is radiated from the left or lampblack face of the hot cylinder, the portion absorbed by the right or tin face of the cylinder on the left hand gives the absorbing power of tin. Again the left or lampblack face of the right cylinder receives all the rays emitted by the right or tin face of the hot one in the middle. This then determines the radiating power of tin. But as the liquid in the two tubes remains in the same level, these two quantities of heat are equal *i.e.*, the absorbing power of a body is equal to its radiating power.

In the figure T denotes tin-face and L, lampblack face.

Let Qb and Qc be the quantities that enter into the canisters B and C respectively, Qb depends *upon the absorbing power of tin* since of the rays emanating from the lampblack face of A, those that enter into B depend upon the absorbing power of tin in B.

Again all the rays that emanate from the tin-face of B are absorbed by the lampblack face of C. Therefore Qc depends upon the emitting power of tin in A.

Now since Qc = Qb, it proves that the *absorbing power of tin is equal to its radiating power.*

QUESTIONS.

1. Mention the chief laws of the reflection of heat (3) prove them experimentally especially in concave mirrors. (4)

2. Explain the principle of the concave mirror (4) what do you understand by the term 'focus' 4

3. Describe the experiments by which reflecting, absorbing, and radiating powers of bodies have been determined. (6, 7)

4. Mention the causes which modify these powers. (8) Describe Ritchies' experiment to prove the equality of radiating and absorbing powers. (9)

5. How did Melloni prove that the reflecting power varies with the density ? (8)

6. Prove by experiment that the gases in a state of combustion possess very little radiating powers.

STEAM ENGINES.

1. **Steam Engines** are based on the elastic force which aqueous vapours exert at high temperatures, and on the condensation of the vapours by cooling.

History of Engines.—Hiero first invented a machine called **Eolipyle,** worked by the steam. It is analogous to Hydraulic Tourniquet. It consists of a hollow sphere rotating on two pivots, which has two tubulures fixed to it on two points at the extremities of a diameter. These tubulures have each an opening for the passage of steam in opposite directions. The sphere is partly filled with water, a part of which is converted into steam on the application of heat. This steam issues through the two apertures in opposite directions and rotates the machine.

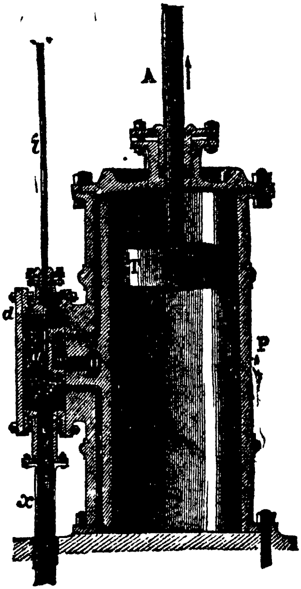
Papin then constructed another machine.—It consists of a cylinder closed at the bottom and open at the top, a piston working in it. A little water is poured into the vessel, when it is placed in a furnace the piston ascends by the elastic force of the steam produced by the heat. The piston is made to descend by cooling the cylinder, when the vapour is condensed into water again.

Newcomen and **Cawley** made a machine for the purpose of draining mines. In this engine the steam is produced separately in a boiler placed below the cylinder and connected with it by a tube having a stopcock. When the cock is turned, steam enters the cylinder and makes the piston ascend. The piston is made to descend by condensation, which is produced in it by injecting the water into the cylinder from a tank placed at a higher level, and connected with it by a tube having a stopcock. The water, after condensing the steam, flows out through an opening at the bottom. This opening is connected with a bent tube having a valve closing the other end. In this machine there is a considerable loss of energy, because the heat of the steam is first used up in heating the cylinder before raising the piston.

Watt improved upon the plan. **First** he used *a separate vessel* as a *condenser* which was connected with the cylinder by a tube provided with a stopcock ; into this vessel water was injected, so that a great loss of heat was saved. Here the application was made by him of the fact that in the two communicating vessels one containing water at o·c and the other at 100·c, the elastic force is uniform throughout and is the same as that in the vessel containing water at o·c. *Next improvement* was that *he closed the cylinder* ; so that in his engine piston was not made to descend by atmospheric pressure as in Newcomen's engines. There was a saving of heat again, for it prevented the air from entering into the cylinder thereby cooling it.

His single acting Engine. It is so called because the *steam acts only on one side of the piston.* In this he caused the vapour to act above the piston so as to make it descend, then by means of stopcocks alternately open and closed by the action of the engine itself, the steam passed simultaneously above and below the piston and pressed it equally in opposite directions so that it remained in equilibrium. A counterpoise on the other side of the lever connected with the piston-rod caused the piston to ascend. It had the great disadvantage that it had no real force except when the piston was descending, so that by means of it only pumping action could be performed.

His double acting Engine—In it the steam *is made to act alternately on the two faces of the piston.* By a system of stopcocks, open and closed by the engine itself, it was so arranged that when the lower part of the cylinder communicates



with the condenser, the upper part is connected with the boiler and the *steam acting above causes the piston to descend.* When the piston is very near the bottom of its stroke, the top of the cylinder communicates with the condenser and the bottom with the boiler. The *steam now entering below causes the piston to ascend.*

Other parts of the engine, their uses. Besides *these—he introduced air-pump*, *feed-pump*, *cold water-pump*, *regulator* and *parallelogram* in his machine.

The *function of the air pump* is to remove the air from the cylinder as well as water from the condenser. The water in the condenser after a time becomes hot by the heat which the steam in condensing gives up to it, and refuses to condense the steam any longer. The airpump removes this hot water from the condenser; and *cold water pump* which is used in connection with the engine, raises from some source the cold water, which replaces the hot water withdrawn from the condenser. Again the air which is dissolved in cold water, is liberated in the boiler where the water is heated; it soon passes above and below the piston and stops its motion. The *airpump* removes this air also. The *feed pump forces into the boiler the hot water* withdrawn from the condenser by the airpump and thus saves a great deal of heat. The *function of the regulator* is to *regulate the quantity of steam that* passes into the cylinder, admitting more when the machine works slowly and less when it works rapidly. The *parallelogram imparts rectilinear motion to the piston rod.*

QUESTIONS.

1. On what principle is the steam engine constructed ? (1)
2. Give a concise history of the steam engines from Hiero's Eolipyle to Watt's single acting engine. (2)

3. What are the advantages of Watt's double acting engine? (3) Mention all the improvements that have been made by him. (3)

4. Name the different parts of the engine and state their uses. (2)

SOURCES OF HEAT.

1. The various sources of heat are, (1) the **mechanical sources**, which are *friction*, *pressure* and *percussion*, (2) the **physical sources,** comprising *solar radiation*, *terrestrial heat*, *molecular action*, *changes of condition* and *electricity*, (3) The **chemical sources** *i.e. molecular combinations.*

2. Heat due to friction.—That the friction of two bodies produces heat is known to every body; if two pieces of metal be rubbed together, they will be heated after a time. Davy melted ice by rubbing two pieces of it in a vacuum and arguing from this experiment he exploded the material theory of heat. *To illustrate* this a brass tube partially filled with water and well corked is made to rotate by means of a wheel and a strap placed round them both. While it rotates it is clasped by a squeezer. Heat is produced by the friction of the squeezer and the tube, which boils water and the cork is driven out by the vapour produced by boiling. *In friction* the *quantity of heat produced varies directly with the pressure* and *the rapidity of motion.*

3. Heat due to pressure.—When two bodies are pressed together heat is produced, which depends upon the amount of pressure, and if one of the bodies be compressible, heat depends upon the diminution of volume. *To illustrate the production of heat by the compression of gases, a pneumatic syringe* is used. It is a syringe made of very thick glass and its piston is very air-tight. There is a cavity at its bottom, in which a small piece of tinder is placed. The tube being full of air, when the piston is suddenly pushed inward, the air is compressed and heat is produced by this pressure, which ignites the tinder and a bright flash is seen. *Heat due to percussion is illustrated* by hammering a small piece of iron which after a time becomes very hot. In firing a shot at an iron target, flame is seen at the moment of impact.

4. Chemical sources.—When two bodies unite together to form a *chemical compound* (*i. e.*, a body entirely different in properties from the former two), heat is always and light sometimes evolved, but it is imperceptible in slow combination because it is dissipated as soon as it is formed. *Combustion* is the chemical combination attended by heat and light. A *flame* is a gas or vapour raised to a high temperature by the heat of chemical combination. The temperature of a flame does not depend upon its luminosity, for the hydrogen flame which is scarcely seen in day light, has the greatest heat.

5. **Calorimeter** is an instrument used to determine the amount of heat in any body. *Combustion Calorimeter* measures the amount of heat produced by chemical combination in a body. *Rumford's Combustion calorimeter* consists of a metallic box containing a known weight of water at a known temperature. Through it passes a long spiral copper tube, one end of which terminates in an inverted funnel outside the box and the other end remains open and passes through a side of the box. The body whose heating effect is to be determined is weighed, placed beneath the funnel and lighted. The gaseous products pass through the spiral tube, impart their heat to the water and raise its temperature. From this heat of combustion can be determined.

SOURCES OF COLD.

6. The **various sources of cold** are, (1) expansion of gases; (2) *radiation of terrestrial* bodies in general; (3) **the passage of a body from** the solid to the liquid state or from the liquid to the gaseous state.

7. **Cold produced by the expansion of gases**—When a gas is rarified, a reduction of temperature, often takes place. *It can be illustrated* by placing a thermometer under the receiver of an airpump, at each stroke temperature is seen to fall. When the air is again allowed to enter into the receiver, temperature rises to the original point. The *explanation* is that in expansion molecules overcome their mutual attraction through a certain space; therefore a certain amount of work is performed, which requires the consumption of an equivalent quantity of heat. This heat is taken from the body itself and the consequence is the fall of temperature. Ice can be manufactured on this principle by placing a vessel containing compressed air at an ordinary temperature in a cold volatile liquid in which a bucket of water is also immersed. The air on being allowed to escape cools the liquid to a temperature sufficient to freeze the water.

8. **Cold produced by radiation**—Bodies radiate heat at all temperatures and the earth radiates more in the night, (for during the day its radiation is more than compensated by the

heat of the Sun): this radiation lowers its temperature during the night. Whatever increases radiation, increases cold to that extent. At Hooghly *ice* was at one time *prepared by nocturnal radiation*, by placing shallow pans of water on non-conducting bodies, as straw and exposing them to the clear sky.

QUESTIONS.

1. Enumerate the various sources of heat. (1)
2. Describe the apparatus which illustrates the production of heat by friction. (2)
3. Give two examples of heat produced by *pressure* and *percussion*. 3
4. Define chemical combination, combustion and flame, and describe the construction of *Rumford's Calorimeter*. 4, 5
5. What are the chief sources of cold ? (6) Give some examples of cold produced (*a*) by expansion (*b*) by nocturnal radiation. 7,8
6. In Bengal the nocturnal radiation is used in manufacturing ice. Explain the principle. 8

OPTICS.

1. Optics treats of the properties of light. **Light** *is the immediate external cause of our visual sensation.* It acts upon the retina of the eye. **Luminous bodies** are *such as emit light* and *sometimes generate it ;* they are independent sources of light ; those that are not self-luminous receive the light by which they are seen from the luminous ones, so they are not visible in a dark-room. **Light** *may* then also *be defined to be the agent whose presence is necessary to render non-luminous bodies visible in a dark-room.*

We have already seen in the chapter on radiation that the amount of heat radiation increases with the temperature. But if an iron wire is made gradually hotter by passing an electric current through it, when the temperature reaches a certain point (at dull red heat), we begin to be aware of something else. The body becomes visible. In addition to the heat rays, the body now begins to radiate rays which effect our eyes and produce in us the sensation of vision. Thus heat and light are forms of the same kind of energy. They differ in degree only, and according to the theory they differ from each other only in the length of the waves which produce them. But this difference in degree produces difference in the nature or quality of the radiation, for the wave now begins to affect the system in an entirely different manner (*i.e.* instead of producing the sensation of warmth it produces the sensation of vision).

2. Definitions—Transparent *bodies are those which transmit light* and *through which objects are distinctly seen.* **Translucent** *bodies also transmit light but objects cannot be distinguished through them.* **Opaque** *bodies do not transmit light.*

All bodies absorb,.more or less, a portion of the light which impinges on them. There is *not a perfectly transparent body in this world.* Again for the same body the *transparency decreases with the increase of thickness.* Air is very transparent, but it weakens light when its thickness is increased sufficiently. Again *a perfectly opaque body is not to be found,* for when *sufficiently thin, every opaque body transmits light to* some extent.

A luminous ray is *the line of light and its direction is that in which the line is propagated.*

A luminous pencil *is the collection of rays from the same source.* It may be **parallel, divergent or convergent.**

The point to which the rays converge is called the *focus* of the pencil.

It is said to be *parallel*, when *it is composed of parallel rays* ; *divergent*, *when the* rays seem to *separate from one point* as they proceed, and *convergent*, when they tend towards the same point.

A parallel pencil may be considered as diverging from an infinitely distant source (as the sun or stars) or as converging to a point at an infinite distance. Light which proceeds from any source at a very great distance may be regarded as parallel for all practical purposes.

A **focus** is a point from which rays of light diverge or seem to diverge or to which they converge.

A **medium** is *any space or substance which light can traverse.* It is said to be **homogeneous** when *the composition and density of the substance are the same in all parts.*

The **colour of light depends** upon its **quality** *i.e.*, according to the theory upon the wave length of the light-waves emanating from the luminous body.

3. Theories.—In order to explain the phenomena of light, several theories have been advanced, the most important of which are the **emission** theory and the **undulatory** theory. On the **emission theory** light is supposed to consist of small imponderable particles, shot out by luminous bodies in all directions, in right lines and with almost infinite velocity. They are of extreme tenuity and are fine enough to pass through the pores of transparent media. Crossing the humours of the eye, they act on the retina, and produce the sensation of vision. Newton was the chief supporter of this theory. The **theory of undulation.** On this theory it seems necessary to assume the existence of an imponderable medium of extreme elasticitv and tenuity, called the *luminiferous ether* which fills space (interplanetary and vacuous), surrounds the atoms of bodies and extends without solution of continuity through the humours of the eye. The theory supposes that the molecules of luminous bodies are in a state of vibration ; the vibrations are taken up by the ether, and transmitted through it in all directions in the form of spherical waves in a homogeneous mediun. These waves impinging on the retina excite the sensation of light.

The *vibrations* of the ether take place *in a plane at right angles* to the direction of propagation. *Luminous vibrations* are therefore *transverse* and not *longitudinal* as sound waves are. It is the *propagation of a form* and not the transference of the substance which *constitutes the wave.* In this theory the ray has no material existence, it is merely a direction. This theory was enunciated by Huyghens and Euler, and afterwards supported and developed to its present state by Young and Fresnel.

4. *Objections* to the *emission* **theory** are : (1) the assumption that light moves with the *same* velocity whatever be the mass of its *source*, renders it probable that light does not consist of material particle, for then, taking gravitating forces of different masses into account, the particles of light will be pulled back differently, and consequently the velocities cannot be the same. (2) It inevitably follows from the theory that the bending of a ray of light towards the perpendicular is accompanied by an increase of velocity (*i.e.* the higher the refractive index, the greater is the velocity of light) ; for it is supposed that when a particle of light approaches a refractive surface *obliquely*, it is drawn towards the surface with a certain force, consequently the velocity of the particle is increased. (It enters the refracting medium with this increased velocity and once within the medium, the attractions before and behind the particle being the same neutralise each other, and the increased velocity, is maintained.) According to this theory then light ought to move with greater velocity in water than in air. But it has been demonstrated by rigid experiments that light moves more slowly in water than in air, and generally that the velocity diminishes as the index of refraction increases. Therefore the theory falls to the ground. (3) The phenomenon of interference, (*i.e.* the fact that two beams of light acting on each other produce darkness,) cannot be explained by the theory, for the superposition of two particles cannot annihilate both.

a. The **advantages** of the **undulation** theory.—It accounts for all the phenomena, (such as diffraction, interference, polarisation &c..) that cannot be explained by the other theory ; it proves that the phenomena of heat and light are closely allied, differing only in degree and not in kind, (heat in its higer state of vibration being light). The theory also shows the analogy between light, sound and other wave-motions.

5. When a pencil of light from one medium meets the surface of another, a portion of it enters into the second and the remainder is thrown back. The portion that enters into the body is again partly **absorbed** and partly **transmitted**. Of the portion that is thrown back, some are done so *irregularly* in all directions and, are said to be **diffused,** while others are thrown back *regularly* in *one direction* and are said to be **reflected.**

If I denote the quantity of light falling on a body ; D = the quantity *diffused* ; R, *reflected* ; T, *transmitted* ; and A, *absorbed* $I = R + D + T + A$.

D is comparatively very small and generally neglected, the equation then becomes $I = R + T + A$.

In *transparent* bodies A is *Zero* $\therefore I = R + T$.

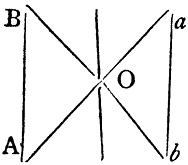
In polished opaque bodies T is Zero $\therefore I = R + A$.

RECTILINEAL PROPAGATION OF LIGHT.

6. *Light is propagated in a right line in a homogeneous medium.*

Direct or experimental proofs. (1) A luminous object is seen by means of the rays which it sends to the eye, but if an opaque body be placed in the right line which joins the eye and the luminous body, the light is intercepted. (2) Also if two screens, each pierced with a hole, are so arranged that these holes are in a right line with the flame of a candle, an eye placed in this line behind the screens is able to see the flame. But a slight displacement, either of the eye, the candle, or one of these screens, puts the flame out of sight. (3) When light enters into a dark room by a small hole, a narrow luminous beam marks its course, on the dust particles, flying in the room ; the track of this beam is always perfectly straight. A *luminous body also emits light in all directions*, for the object is seen from every point round it. *Light changes its direction on meeting an object which it cannot penetrate* (then it is said to be *reflected*) ; *or when it passes from one medium to another* (then it is said to undergo *refraction.*)

7. **Indirect proofs.** (1) One of the results that follow from the rectilineal propagation of light is that *when light from an illumined object enters into a darkroom, through a small aperture, it gives an inverted image of the object* on any white screen placed in the room in front of the aperture. The image is *inverted* because the rays *cross each other* at the aperture. The outlines will be sharper in proportion as the hole is smaller. Let A-B be an object, O the aperture, and *b*, *a*, the screen.



Draw B O, it represents a ray of light from B ; this when produced will meet the screen at *b*, similarly A O will meet at *a*. Consequently the image of A B will fall inverted on the screen.

Experiment.—Take a candle and a screen, and between these place a card with a pinhole in it, an inverted image of the candle falls on the screen.

8. Shadow—(2) As a consequence of the rectilineal propagation of light, *opaque bodies cast shadows.* Or more strictly the *actual* or physical *shadows* of bodies *coincide with* the geometric shadows or *projections of* them *on the screen.*

When an opaque body is placed in the path of a luminous pencil, the **shadow** of the *body is the spacee behind it from which light is either entirely* or *partially cut off.* The **umbra** or perfect shadow is *that portion* of the shadow *from which light is entirely cut off.* The **Penumbra** is *that portion* of the shadow from which *light is partially cut off.* It receives light from one portion of the luminous body but light from the other is intercepted, so that it is partly lighted.

When the *source of light* is a *mere point* the *shadow* is *perfect,* there is no penumbra. In this case the shadow of a sphere placed in the light is the part behind it of a *divergent cone* sharply defined, whose apex is the point and base the screen on which the shadow falls.

But when the *source of light* is a *luminous surface,* for instance a globe, *the umbra* or the *perfect shadow will be fringed by* an *imperfect shadow* called the *penumbra.* In order to determine the shadow of a sphere in this case, draw two cones of shadow touching the sphere, one from the highest point of the globe and the other from the lowest point. These two will partially overlap each other. The part behind the sphere which is common to the two, and is *not* penetrated by light rays, is umbra, the rest is penumbra. The *penumbral* cone is *always divergent.* The *umbral* cone is *divergent* when the *opaque body* is *larger than the source of light. It* is *convergent* when the opaque *body* is *smaller than the source.* It becomes a *cylinder* when the *two* are of the *same size.* Therefore when the *luminous body* is *smaller than the opaque one,* the *umbra* gradually *increases* in size as *the distance* of the screen from the opaque body *increases.* But when the *luminous* body *is very large compared with the opaque body,* as in the case of the sun illuminating the earth. The *umbra gradually diminishes* and *tapers off to a point* so that *beyond a certain point,* the whole of the light is never intercepted and *no umbra exists.* This explains why the bird at some height in the air casts no shadow.

VELOCITY OF LIGHT HOW TO MEASURE IT.

9. **Romer's Method**—That light requires time to pass through space was first proved by an eminent Danish Astronomer named Romer while engaged in observing the eclipses of Jupiter's satellites.

It happens that the satellite nearest to Jupiter passes into the shadow of the planet at regular intervals (48½ hours) and is thus eclipsed. The period between the two successive eclipses gives the exact time of its revolution which remains constant. Therefore if the earth were at rest the successive eclipses of the satellite would have been observed to occur at regular and equal intervals after each revolution. But as the earth is always moving in its orbit its distance from the planet always changes. When the earth is moving away from the planet, this distance continually increases, so that during this time if the eclipse is observed when the earth is nearest to Jupiter, the intervals between successive eclipses will gradually increase ; for as the earth changes its position, each time light has to travel a little distance more, which is equal to the part of the orbit (resolved in the direction of the ray) travelled by the earth during the interval. This interval or period continually increases and reaches its maximum when the earth is on the opposite side of the orbit (*i.e.* at the other extremity of the diameter) and at the greatest distance from the planet. At that point the total increase in the period of revolution was observed to be 16 minutes 26 seconds, so that an eclipse seen at this point was 16 minutes 26 secs later than if had been observed at the point where it was nearest to Jupiter. This difference is due to the time taken by the light in travelling across the diameter of the earth's orbit. As the diameter of the orbit is known, the velocity is calculated by dividing the diameter by the time.

After this Bradley determined the velocity from the aberration of stars. It has also been determined by Foucault and Fizeau by experiments over terrestrial distances.

PHOTOMETRY.

Definitions—The province of photometry is to measure as well as to compare the illuminating powers of different sources of light.

The **illuminating power** of a source of light *is measured by the quantity of light which emanates from the unit area of the source* in the unit of time.

The **intensity of illumination** of a given source of light on a given surface *is the quantity of light which falls on a unit area of the surface.*

Laws—The intensity of illumination obeys the following laws—(*i*) *The intensity of illumination at a certain distance is directly proportional to the illuminating power of the source of light.*

(ii) The intensity of illumination on a given surface is inversely proportional to the square of its distance from the source of light.

(iii) The intensity of illumination, which is received **obliquely** *is proportional to the* **cosine** *of the angle which the luminous rays make with the normal to the illuminated surface.*

10. Experimental proof of the 2nd law or the law of inverse squares—Cut a square piece of paper to the size of A, and another to the size of B, which is *four* times that of A. Place the two in the path of the rays proceeding from the source S. If A is placed at a certain distance and B at *twice* that distance, they will intercept or block out the same amount of light ; this is seen from the fact that their shadows on any screen will coincide. Thus the same amount of light which falls upon A is, at *twice* the distance, spread out over B, which has *four* times the area. Therefore the intensity of illumination, (or amount of light on the same area) at the distance of B, is only *one-fourth* of that at A. Similarly when another piece of paper whose area is *nine times* that of A is placed at *thrice* the distance, it would block out the same quantity of light. Thus the intensity of illumination at *thrice* the distance is *one-ninth.*

Therefore in general *intensities of illumination are inversely proportional to the squares of the distances from the source.*

For a general proof of this statement see (Radiation).

All this depends upon the fact that light travels in straight lines ; from which it follows that when the pencil is divergent the areas of perpendicular sections of the pencil are proportional to the squares of their distances from the source, when the latter is a mere point.

The limitations under which the statement is true—The above law holds good exactly (1) when the *source* of light is a mere *point* so that the pencil forms a cone with this point as its vertex *i.e.*, the *rays are divergent.* (2) When the *light falls normally on the surface.*

In case *of parallel rays the intensity remains unchanged at all distances.* The decrease of luminosity (with the increase of distance) in this case is due to the absorption of light by the medium.

It follows from the law of inverse squares that the **illuminating powers** *of two sources of light are directly* **proportional** *to the* **squares** *of their* **distances** *from a given surface where their intensities are the same.*

Let P_1 and P_2 be the illuminating powers of the two sources; d_1 and d_2 their respective distances from the screen; and I_1 and I_2 their respective intensities at the distance of the screen. Then

$$I_1 = \frac{P_1}{{d_1}^2} \text{ and } I_2 = \frac{P_2}{{d_2}^2}$$

When their intensities are equal *i.e.*, when the screen is equally illuminated, $I_1 = I_2$

$$\therefore \quad \frac{P_1}{{d_1}^2} = \frac{P_2}{{d_2}^2} \text{ or } \frac{P_1}{P_2} = \frac{{d_1}^2}{{d_2}^2}$$

This proves the statement.

Note for student.—The student should bear in mind the distinction between this statement and the law of inverse squares.

11. Rumford's shadow Photometer—It consists of an opaque vertical rod fixed in front of a white vertical screen. In it the *intensities of illumination* on the two adjacent portions of a screen are measured by comparing the *depths* (or intensities) of two shadows, for each shadow is only a *partial* shadow *i.e.*, the part of the screen on which the shadow due to one light falls receives no light from it, but it does receive light from the other source. Therefore in comparing the depths of shadows we really compare the intensities of two adjacent portions of the screen.

a. **To compare the illuminating powers.**—Take two sources of light, place them on the same side of a screen, and adjust their distances so as to produce shadows of equal depths on the screen. The two lights should be placed in such a manner that the two shadows are formed side by side so that their intensities can be easily compared ; when this is the case the intensities of illumination of the two sources at the distance of the screen are equal.

Measure off the two distances, then from what has already been proved, the illuminating powers will be directly proportional to the squares of these two distances.

b. **To verify the law of inverse squares.**—Place one candle at a certain distance from the screen and *four candles* in a row parallel to the face of the screen at *twice* the distance on the same side of the screen. When this is the case it will be found that the depths of the two shadows will be equal. This proves that the intensity of one candle at a certain distance is equal to the intensity of four candles at twice the distance. Therefore the intensity diminishes four times as the distance increases two-times. Similarly *nine candles* should be placed at *thrice* the distance to produce the same effect. This proves the law.

12. Bunsen's Photometer.—It consists of a piece stoutish white paper mounted on a suitable frame. There is a greased or oil spot at the centre. It *depends upon the principle* that *when* a sheet of *paper* with a greased-spot *is* placed *between* the *observer* and *a light* the *spot* appears *brighter*; but when the *light is* placed *between* the *observer* and the sheet, the *spot* will appear *darker*. The reason is that light that reaches the eye of the observer is what is reflected from the sheet. As greased paper is more translucent, the greased portion transmits greater quantity of light than the remaining portion. In the first case when the light is placed on the same side with the observer, this greased portion transmits more rays of light than the rest, consequently it sends less rays to the eye than the remaining portion, therefore it appears darker. In the second case when the sheet is between the light and the observer, the greased spot will send more rays to the eye than the remaining portion which is less translucent, consequently it will appear darker. When it is used for purpose of comparing the illuminating powers of different sources of light *e.g.*, coal-gas &c., the sources of light to be compared are placed on the two sides of the screen, and their distances adjusted so that the spot is as nearly as possible invisible on both sides of the screen. The spot then appears neither darker nor brighter than the rest of the screen. In this position the amount of light that is lost by transmission from the source on the same side is exactly compensated by the amount gained by transmission from the source on the other side. Therefore the intensities of these two lights at the distance of the screen are equal. Now if we measure off the distances, the illuminating powers of the two lights can be determined, since they are directly proportional to the squares of these distances.

a. **To demonstrate the 3rd law,** 1st suppose the screen is placed perpendicular to the axis of the cone from the luminous point, a the area of the circle which forms the base of the cone on the screen. Then $i=\frac{Q}{a}$. Next place the screen obliquely at an angle θ with the screen in the 1st position, then the area cut off by the same cone is $\frac{a}{\cos\theta}$, but the quantity received is the same

Therefore the intensity $i' = \frac{Q \cos \theta}{a}$

$$\therefore \quad \frac{i}{i'} = \frac{Q}{a} \times \frac{a}{Q \cos \theta} \text{ or } i \cos \theta = i'$$

13. **Sources of light, phosphorescence.**—The *various sources* are the **sun,** the **stars, heat, chemical combination, phosphorescence, electricity** and **meteoric phenomena.**

The origin of the light emitted by the sun and stars is not known. On the undulation theory, *heat and light are caused by the same kind of vibrations of molecules.* The *difference being* that *light is due to the greater number of vibrations in a time,* as *well as to greater lengths of them.* The fact is that our eye is affected by these vibrations when they are within certain limits, beyond which they cannot excite the sensation of vision their presence is indicated by the thermometer Light emitted in chemical combination is due to the high temperature produced. **Phosphorescence** is the *property possessed by many bodies of emitting light after being exposed to the sun for some time.* This takes place without any sign of combustion or sensible elevation of temperature. Recent investigations have shown that this property exists in a small degree in an immense number of bodies. **Fluorescence** is another *property possessed by a large number of bodies of* changing (generally *lowering*) *the refrangibility of light, when it passes through the solution of these bodies.* This phenomenon appears to be essentially identical with phosphorescence. The *former* name is given to the phenomenon, if the change is observed *while the body is actually exposed to the source* of light, the *latter,* to the effect, nearly of the same kind, which is observed *after the light from the source is cut off.* Both forms of the phenomenon occur in a marked degree in the same bodies; spontaneous phosphorescence is seen in certain vegetables and animals.

C. U. Questions 1. Five equal candles burn in a cluster at one end of a rod, and two similar candles at the other end. How and on what principles would you place a sheet of paper on the rod so as to have equal illumination on both sides?

Let l be the length of the rod, d the distance of the sheet from the cluster of 5 candles; then $(l-d)$ is the distance of the sheet from the other cluster of 2 candles; also let i_1 and i_2 be their respective intensities at the distance of the sheet and P the illuminating however of one candle. Then

$$i_1 = \frac{5P}{d^2} \text{ and } i_2 = \frac{2P}{(l-d)^2}.$$

Since by question $i_1 = i_2$ $\quad \frac{5P}{d^2} = \frac{2P}{(l-d)^2}$

$$\text{or } \frac{5}{2} = \frac{d^2}{(l-d)^2}.$$

$$\therefore \quad d = \frac{l\sqrt{5}}{\sqrt{5}+\sqrt{2}}.$$

2. At what distance of a screen two lights of intensity 3 and 9 respectiveiy must be placed to give equal illumination? Let d_1 and d_2 to the respective distances of the two sources, and i_1 and i_2 their respective intensities at the distance of the screen

$$i_1 = \frac{3}{d_1^2} \text{ and } i_2 = \frac{9}{d_2^2}.$$

Since by question $i_1 = i_2$

$$\frac{3}{d_1^2} = \frac{9}{d_2^2} \text{ or } \frac{1}{d_1^2} = \frac{3}{d_2^2}$$

$$\therefore \quad \frac{d_1}{d_2} = \frac{1}{\sqrt{3}}.$$

QUESTIONS.

1. Explain the two principal theories of light (3). What are the objections to the *emission theory*? (4). Enumerate all the advantages of undulation theory (*a*).

2. Experimentally demonstrate that light passes in straight lines in a homogeneous medium (6). What are the results that follow from it? (7, 8). When does it change its course? (6).

3. Draw a figure to show that rays of light *cross* one another at the aperture, when they enter into a dark room through it (7).

4. What are *umbra* and *penumbra*? (8). Explain the fact that when a bird rises very high up in the air, it casts no shadow on the surface of the earth (8).

5. Describe Romer's method of determining the velocity of light (9).

6. Define *intensity of light* and illuminating power (10) What are the laws which it obeys? (10). Demonstrate them (11, 12). Prove that the 2nd law is not true in case of parallel rays (11). Prove also that illuminating powers of light vary directly as the squares of distances.

7. Describe Rumford's method of determining the illuminating power of light (11 *a*). Describe the principle of Bunsen's photometer (12.)

8. Name the different sources of light? (13). What is phosphorescence?

REFLECTION OF LIGHT.

1. *Reflection* is the change which light undergoes when it meets the surface of a body which it cannot penetrate. The change consists generally in the change of direction. Reflection generally takes place from the surface of polished bodies. *By* means of the *reflected light* the *image* of the *luminous body is seen* and the *reflecting bodies are seen by* the *diffused light.* There is not a perfectly reflecting body in this world, even the best reflectors (as polished metals), extinguish a portion of the light that falls on their surface. *Reflecting power varies with different bodies;* and even *for the same body it increases with the degree of polish* and *with the obliquity of the* incident *ray.*

2. Definitions—**Point of incidence** is the point in any surface on which a ray of light falls.

The **incident ray** is the ray of light which meets a reflecting surface.

The **reflected ray** is the ray which is thrown back (regularly) in a definite direction from the reflecting surface,

The **normal** line is the straight line drawn perpendicular to the reflecting surface at the point of incidence.

The **angle of incidence** is the *angle* which the incident ray makes *with the normal* at the point of incidence.

The **angle of reflection** is the *angle* which the reflected ray makes *with* the *normal.*

3. **The laws of reflection**—The reflection of light is governed by the following two laws:—(1) *The angle of reflection*

is equal to the angle of incidence. (ii) The incident ray, the reflected ray and the normal are in the same plane, which is perpendicular to the reflecting surface.

4. **Experimental demonstration**—The laws may be demonstrated by taking a graduated circle in a horizontal plane and a rotating mirror in the vertical plane, fitted into the hole at the centre of the circle. A long needle is attached to the handle at the bottom of the mirror, and is perpendicular to it. The needle serves as the normal to the reflecting surface. *A ray* of light *in the plane of the circle* is made to fall upon the mirror making a certain angle with the normal. The ray is then *reflected, in the same plane*, from the surface of the mirror. This reflected light may be received on a screen placed on the other side of the normal. The angles on the two sides of the normal are the same.. This method **also proves the 2nd law,** since the incident and the reflected rays are in the plane of the circle which is perpendicular to the plane of the reflecting mirror.

Consequences of the 1st law—The fact that the angle of incidence is equal to the angle of reflection has several important consequences. (1) It leads to the general principle of *reversibility*, which means that if the source were removed to the other end of the ray, the path traversed would be *precisely* the same, *reversed.* (2) It follows from this principle that a *plane reflector* must produce *virtual* images. (3) It follows from the law that, *the angular deviation of a ray reflected from a plane rotating mirror is twice the angle through which the mirror rotates.* This fact makes a *rotating mirror* an invaluable instrument in measuring small motions *e.g.*, the small deflection of a magnet in a mirror galvanometer; the amount of expansion of a solid bar by heat. We are familiar with the lever-index used in the latter case, (See Pyrometer) but in practice we are fettered in this method of magnifying small motions, by the weight and other mechanical imperfections of an index-pointer of great length. In the method of *luminous projection* in which the reflected ray is used as the index-pointer, we have a double advantage, we can increase the length of the pointer to any extent, since it is absolutely straight and weightless ; also the angle being doubled the deviation is magnified two times.

5. *The angle through which the reflected ray is deviated is twice the angle through which the mirror rotates.* **A proof** of this is given below. Suppose at first the incident ray is perpendicular to

the mirror; since the angle reflection of is equal to the angle of incidence, the first is reflected back in the same direction and there is no deviation. Next suppose that the mirror rotates through θ (the direction of the light remaining unchanged.) Now the incident angle becomes θ, the angle of reflection is θ also. Since the direction of the reflected light coincided with that of the incident light in the 1st case, the deviation of the reflected light will be 2θ. This proves the law.

The above principle is practically applied in a somewhat modified form to Hadley's Sextant. This instrument is based upon the principle that if there be two reflecting planes inclined at a certain angle, the deviation of the ray reflected once by each of these planes is twice the inclination of the planes.

6. Diffusion.—When *light is irregularly reflected in all directions it is said to be* **diffused**. It depends upon the fact that *bodies* are never perfectly smooth, but *present an infinity of small faces variously inclined* and *which reflect light in several directions*. Diffused light plays an important part in the phenomena of vision, for while luminous bodies are visible themselves, *opaque bodies are only so in consequence of the diffused light*. That *bodies* are *seen by the diffused* and not by the reflected rays, may be *demonstrated* by means of a perfectly polished mirror. When this is placed in the path of light the eye does not perceive the image of the mirror, but of the sun or any other body emitting light. But if the reflecting power of the mirror be decreased by sprinkling chalk powder on it, the image of the sun becomes feebler and the mirror becomes visible.

7. With reference to light another fact must be borne in mind, that *the object is seen only in the direction in which light enters our eyes*. Therefore in the case of reflected and refracted rays the object is not seen in its proper place but in the direction in which the rays enter into our eyes.

QUESTIONS.

1. Define—Reflection of light. How does it differ from diffusion? (1). What are the two laws of reflection? (3). Experimentally demonstrate them (4).

2. Prove that in a rotating mirror the angular velocity of the reflected light is twice that of the mirror (5). What is the principle of Hadley's Sextant? (5).

3. What is diffusion? How is it caused? What important part does it play in the phenomenon of vision? (6)

4. Why is it that the object appears to be displaced from its proper position when seen by reflected or refracted light? (7)

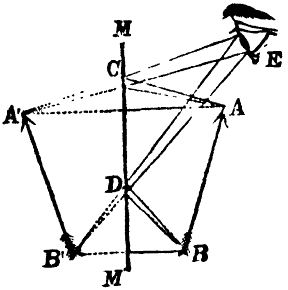
MIRRORS.

1. **Mirrors** are *bodies with polished surfaces,* which show *by reflection the objects that are presented to them.* The *mirrors of the ancients* were of metal, usually of the compound now known as the *speculum metal. Looking glasses* date from the 12th century. They are plates of glass, coated at the back with an amalgam of quicksilver and tin, which forms the reflecting surface. The glass only has the effect of giving the metal, the necessary polish and of preserving it from external agencies, (such as air and moisture) which tend to oxidise it.

2. **Images**—According to the nature of their surfaces *mirrors* are *divided* into **plane** and **curved.** The **image** is the *representation of the object or its form as perceived by us from the rays entering our eyes. It appears* at the place at which the *rays* after reflection or refraction *actually meet* or (in the case of divergent rays) *from* which they *seem to proceed,* so that if produced they will meet there. *Images* are of *two* kinds **real** and **virtual. Real images** are those that *are formed by the reflected or refracted rays themselves i.e.* where the rays after reflection or refraction *actually* meet. They *can be received* on the *screen.* The **virtual images** are the *points from which* the *rays after reflection* or refraction *seem* to *emanate,* so that they appear to be, as it were formed by the *prolongation of the reflected or refracted rays.* They are only optical delusions and *cannot be received on the screen.*

3. **Reflection from plane mirrors.**—By a plane mirror we mean any *plane reflecting surface.* Its *effect is to produce behind the mirror, images exactly similar, both in form and size,* to the real objects in front of it. This is easily explained by the laws of reflexion. Suppose a luminous body emits a divergent pencil, which falling on the mirror is reflected there. But each ray of the pencil retains after reflection, the same obliquity as before, with reference to the mirror, (only on the opposite side of the normal.) Hence it is evident that the reflected rays have the *same* divergence as the incident rays and if produced backward would meet in a point. The image appears to be situated at this point.

4. **The position of the image**—The *image is as far behind the mirror as the object is in front of it.* It can be easily proved.



Take two rays A C and Ac issuing from A and meeting the mirror at C and c. AC is reflected in the direction C E$_1$. Produce this line so as to meet the normal line, produced at A$_1$. The line A^1 shall be bisected by the mirror. For, ACD is equal to A^{1}CD (each of them being complement of the incident and the reflecting angles.) Also each of the angles at the point where the normal line meets the mirror is a right angle. Therefore A^1 is equidistant with A. Similarly it can be proved that all the rays produced will meet at A^1; therefore the image of A is produced there. This is true of every other point.

Rule.—The position of the image of a point in a plane mirror is found by drawing a perpendicular from the point to the mirror and producing it behind the mirror until its length is doubled.

5. Images in plane mirrors—They are **virtual, erect, equidistant** with the object, (*i.e.* at the same distance behind the mirror); and consequently of the **same magnitude** with it and **virtual.** The image is merely a *lateral inversion* of the object. By which we mean *that every thing on the right side of the object will appear on the left side of the mirror.* Every transparent object reflects a sufficient amount of light to produce distinct though feeble images. Thus on the borders of a pool, are seen, formed in the water, the symmetrical images of objects.

6. Multiple images.—An object placed between two mirrors enclosing an angle yields a number of images. Either of the mirrors used by itself would give only *one image.* Therefore the effect observed must be due to the joint action of the mirrors, by which the light is repeatedly reflected from one mirror to the other and finally to our eye. The number of images depends upon the angle enclosed by the mirrors; the smaller is the angle, the greater the number of images. The construction of *Kaliedoscope*, consisting of three glass mirrors enclosed at an angle of 60°, depends on this principle. When the angle between the two mirrors becomes zero, *i.e. when the mirrors are parallel,* *the number of images is infinite.* Practically we see *between two parallel* mirrors *a long succession of images.*

When the angle between the mirrors is contained an *exact* number of times in 360°,

the *number of images* $= \dfrac{360}{\text{angle between the mirrors.}} - 1$

In any other case the number is to be determined by a geometrical construction.

Let M_1 and M_2 be the two mirrors hinged at O, and L the position of the luminous body ; with the centre O and radius equal to OL, describe the circle M_1, M_2 ; Produce M_1 M_2 to *m* and *n* respectively. The circle is divided into four parts. When an object or image is situated within *mon* it is behind the two mirrors, therefore it does not give any image, when it is within *no* M_1, it is in front of M_2 so that it yields an image by reflection from M_2 ; similarly when it is within *mo* M_2, it is in front of M_1, consequently it yields an image by reflection from M_1.

Now draw from LI_1, Li_1 perpendiculars to M_1 and M_2 respectively. Then I_1 is the position of the 1st image from M_1. Now I_1 is within *no*M_1, so it is in front of M_2.

From I_1 draw I_1I_2 *perpendicular* to M_2, I_2 is the position of the 2nd image. This image is within *mo*M_2 therefore it yields a third image from M_1. From I_2 draw I_2I_3 perpendicular to M_1m. Now I_3 is within *nom*, it therefore yields no more images.

Similarly from i_1 draw i_1i_2 perpendicular to M_1m, i_2 is the position of 2nd image ; since i_2 is within M_1on, it yields a 3rd image i_3, situated in this case within *nom ;* i_3 yields no more image.

When the angle between the two mirrors is contained an exact number of times in 360° the two last images (I_3 and i_3 in this case) coincide. This can be easily seen by changing the angle a little, when the angle is diminished, the last image which occupies the middle position is observed to disappear and resolve itself into two images one on each side. On the other hand when the angle is increased, the middle image disappears and the two images nearest the hinge gradually approach and ultimately coincide and form a single image in the middle.

CURVED MIRRORS.

7. Any *curved reflecting surface* is called a *curved mirror* ; when the *surface is a portion of that of a sphere*, the mirror is called *spherical ;* when it is a portion of a parabola, it is called *parabolic.* All *curved mirrors*, are *divided* into **concave** and **convex** mirrors, *according as the reflection* is *from* the *internal* or *external* surface of the mirror.

8. Definitions.—In any *spherical* mirror, *the centre of the* *sphere of* which it is a section is called the **centre of curvature**; when rays pass through this point they fall upon the surface normally, and suffer no angular deviation.

The *central point of the reflecting surface is* called the **centre of the mirror** or the *pole.*

The line passing *through* the *centre of curvature* and the *centre of the mirror* is the **principal axis** of *the mirror.*

Any *line* passing *through the centre of curvature* only is called the **secondary axis**.

The **aperture** is the *angle which the mirror subtends at the centre of curvature.*

The *point where the rays after reflection from a curved surface meet together is* the **focus** *of the mirror.*

The focus is *real or virtual* according as the rays which meet together *are direct or prolonged.*

The **principal focus** of a mirror is *the point of intersection,* after reflexion, *of rays of light parallel either to* the principal axis or any secondary *axis.*

The *principal focus* then *is the focus of parallel rays.* When *the point* is *in a secondary axis,* it is called a *secondary focus.* This point is midway between the mirror and its centre of curvature.

The **focal length** of a mirror is *the distance of its principal focus from the centre of the figure.*

The **Conjugate focus** of a mirror is the *point of intersection,* after reflexion, *of rays of light emanating from* a luminous point, situated either on the principal or secondary axis.

Conjugate Foci with respect to a mirror are *points so related that one is the image of the other in the mirror* ; so that when a body is placed at one focus its image is formed at the other ; and when it is taken to the other point (where the image was before), its image is formed at the point where the body was before.

The conjugate foci are *real,* when the rays proceeding from the one pass through the other after reflection. When one of the conjugate foci is *virtual,* the rays of light appear to diverge from that point, but do not actually pass through it.

9. In its reflection from curved mirrors light obeys the law already established for plane mirrors ; for *any curved mirror may be supposed* to *be made up of an infinity of small plane surfaces* all equally inclined to each other so as to form the curved surface

10. It has been already stated that rays may be either divergent, parallel, or convergent. *Rays issuing* from *terrestrial* *objects are* necessarily *divergent ; those from* the *sun and stars* are, in consequence of the immense distance of these objects, sensibly *parallel.* By suitably reflecting them from curved mirrors, we can render the *terrestrial rays of light*, *parallel or convergent*, This is done especially by *concave* mirrors. *Convex* mirrors always render pencil *divergent* after reflection.

11. Reflection from concave mirrors—Since the angle of incidence is equal to the angle of reflection and the radius of curvature is always normal to the point of incidence, in every case the direct and the reflected rays enclose equal angles with the radius on each side of it. When the luminous *point* is placed *at the centre* of curvature, all the *rays* from the point *strike* the surface, *perpendicularly* and return to the same point, so that the *focus coincides* with the position of the *point.*

When the point is placed *beyond* the *centre*, whatever its distance may be, the *rays* are rendered convergent on reflexion ; they *meet* together at a point *between* the *centre* and the *mirror.*

When the point is at *infinity*, so that the *rays* falling on the mirror are *parallel*, they meet, after reflexion at a point *midway* between *the mirror* and *its centre.*

If the *point* is placed *between the principal* focus and the *centre* of the mirror, the rays after reflection meet at a point *beyond the centre.*

When the object is *at the principal focus*, the rays after reflection become *parallel.*

If the *point* be placed *between* the *principal focus* and the *mirror*, the rays after reflection will be *divergent*, they will not meet together and there will be no real focus ; but if these be produced backwards, they will intersect behind the mirror and form a *virtual* focus.

These *prove* that the *law of reversibility* is true in light (*i.e.* the positions of the object and the image are always exchangeable,) or a ray may be made to trace back the same path under the same condition. Thus we see that while *a point moves from infinity* to the *centre of the mirror*, the *image moves from* the *principal focus to the centre;* and that during the passage of the *point* from *the centre to the* principal *focus*, the *image moves from the centre to infinity.* The image is throughout *real.* But when the *point is* situated *anywhere between* the *principal focus* and the *mirror*, the *image* is *no longer seen* in front of the mirror but behind it and is *virtual.*

12. **Formula for the concave mirror**—Let Q be the luminous point situated on the axis Q A of the spherical mirror ; Q R

any ray incident at R and reflected in the direction R q, cutting the axis in q ; O, the centre, A Q $= u$, A O $= r$, A $q = v$.

Now OR being normal $\angle QRO = \angle qRO$.

$$\frac{QR}{Rq} = \frac{Qo}{oq} \text{ (Euc VI 3)}$$

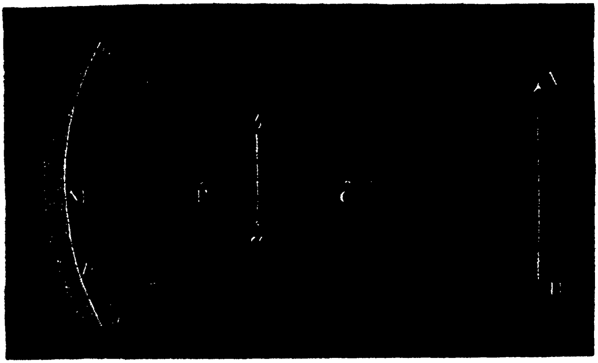
. ultimately when R moves up to A, *i.e.* when the angle is very small QR very nearly becomes QA and $qR = qA$.

$$\frac{QA}{Aq} = \frac{Qo}{oq} \text{ or } AQ.\ oq = Aq.\ OQ.$$

$$u(r-v)+v(u-r) \quad \therefore \quad \frac{1}{v}-\frac{1}{r}=\frac{1}{r}-\frac{1}{u} \text{ or } \frac{1}{v}+\frac{1}{u}=\frac{2}{r}.$$

This formula determines the position of the focus. If the rays be parallel Q is at an infinite distance and $\frac{1}{u}=0$ $\therefore \frac{1}{v}=\frac{2}{r}$ or $v=\frac{r}{2}$ *i.e.* the distance of the principal focus is half that of the radius.

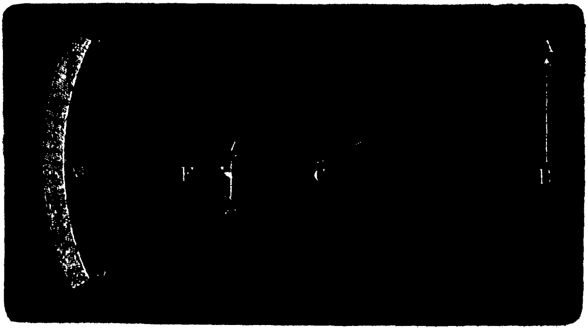
13. Image in concave mirrors—From what has been said it is clear that *concave mirrors* give rise to *two kinds of images real* and *virtual.* Real image is formed (always in front of the mirror) when the object is placed anywhere (up to infinity) beyond the principal focus. When it is *at the principal focus*, *no* image is formed, since the *rays* after reflection *become parallel.* Next, if the



When A B = object ; *ab* = image *i.e.*, when O is beyond C, I is between F and C ; when *ab* = object ; A.B. = image *i.e.*, when O is between C and F, I is beyond C object is between the principal focus and the mirror, the *virtual* image is seen behind the mirror. In order to understand the position and the magnitude of the image, we must bear in mind the fact that if the luminous point is on a secondary axis, the focus is formed on that axis. 1st, take the case when the *object* A·B is *beyond the centre. The image is real*, *inverted*, *smaller* than the object, and placed between the centre and the principal focus. The image is *real*, since the *rays* after reflexion become *convergent*. It is *inverted* since the secondary axis through the point *crosses* the principal axis at the centre, and all the rays from the point, meet, after reflexion, on this axis at a point on the other side of the principal axis. Consequently the image of a point above the principal axis is formed below it, and that of a point below this axis is formed above it. The image therefore becomes inverted. Again since the *magnitude of the object* bears the same relation to *that of the image* as the *distance of the object from the centre* does *to that of the image.*

In this case the *distance of the image* from the centre is *always less than that of the object from it*, the *image* is therefore *smaller* than the object.

Relative sizes of Image and Object—



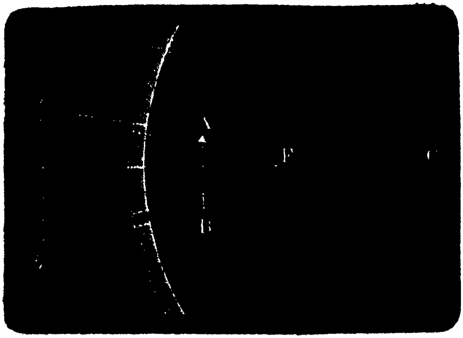
AB = object, $a\,b$ = image
Triangles ABC and abc are similar.

$$\therefore \quad \frac{AB}{ab} = \frac{BC}{bc}$$

$$\therefore \frac{\textit{Linear magnitude of Obj}}{\textit{Linear magnitude of Image}} = \frac{\textit{Distance of obj. from C}}{\textit{Distance of image from C}}$$

Next, when the *object* is placed *between the principal focus and the centre of curvature*; the **image** *is* **real, inverted** and **larger** than the object and is placed *on the other side of the centre.* This is clear from what has been said in the first case and also from the law of reversibility. The image is *larger* in this case, because *its distance from* the centre *is greater* than that of the object.

Lastly, when the *object is between the principal focus and the mirror*—the *image* is **virtual, erect** and **always larger** *than the object.* The image is *virtual,* for the rays after reflection become more divergent, and their prolongations meet together behind the mirror, It is *larger,* since the image being behind the mirror is always at a greater distance from the centre than the object. It is *erect,* because all the rays from any point of the object meet together after reflection at a point on the *same* side of the principal axis.



AB = Object; *ab* = image

14. Table showing the *nature, magnitude and position of the image* for any given position of the object in front of a concave mirror.

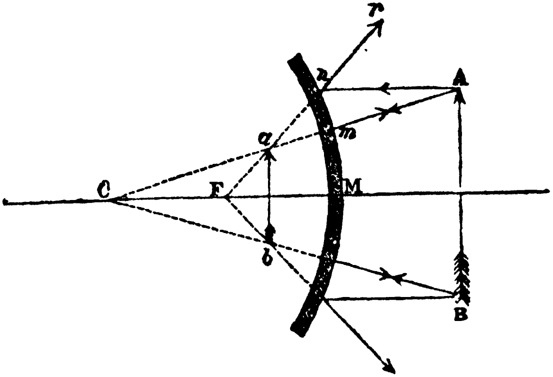
In the following table C denotes the centre of curvature of the mirror, F its principal focus, and M the mirror itself.

Position of object.	Position of Image.	Characteristics of image.
At infinity.	At F.	Real, inverted, diminished.
Beyond C.	Between F and C.	Real, inverted, diminished.
At C.	At C.	Real, inverted equal in size.
Between C and F.	Beyond C.	Real, inverted, magnified.
At F.	Infinity.	no image is observed.
Between F and M.	Behind M.	Virtual, erect, magnified.

N. B.—In *determining the position of the image, draw two lines from any point*, representing the two rays ; *one, parallel to the principal axis*, which after reflexion will pass through the principal focus ; the *other passing through the centre of curvature* which after reflexion will trace back the same path. The *point of intersection of these* two will lines will be *the position of the image* of the point from which the lines are drawn. This is true of every other point.

15. **Convex mirrors**—In the case of a convex spherical mirror, the positions of its foci and of its images are found as in concave mirrors. But all the foci and all the images of a convex mirror are *virtual* ; since the rays after reflection become *divergent*, which on being produced backwards, intersect at points behind the mirror.

Images in convex mirrors.—Whatever be the position of the object, the **image** *is always* **virtual, erect** and **smaller** *than the object.* For in this case the reflected rays are always divergent and their prolongations meet together, on the same side of the principal axis, behind the mirror. The image is always nearer to the centre than the object.



A B=object ; *a b*=image.

16. Determination of the principal focus—To find this *focus with a concave mirror*, it is exposed to the sun's rays, so that its principal axis is parallel to them, then *the point where the image is formed with the greatest intensity* is the principal focus. The *radius* of the mirror is *double this distance.* If *the mirror is convex*, it is covered with paper, but two small portions are left exposed at equal distances from the centre of the figure and on the same principal section. A screen, in centre of which is an opening larger than the distance of the apertures is placed before the mirror. The light is reflected on the parts where the mirror is left exposed and forms on the screen two images. By moving the screen a position is found at which the distance of the images is *double* that of the points. The *part of the principal axis intercepted by the two lines joining images and the points* respectively is the focal distance.

17. Formula for the convex mirror—It can be easily deduced from that for the concave mirror by making necessary alterations in the signs, for if the right side of the mirror is regarded as positive, the left must be negative. In convex mirrors the image is always *virtual* ; v and r are of the same sign, since the image and the centre are on same side of the mirror, while the object being on the opposite side, u is of the contrary sign. Hence the formula becomes

$$\frac{1}{v} - \frac{1}{u} = \frac{2}{r}$$

18. Spherical aberration, caustic—When the *aperture* mirror is very great the reflected rays are not all collected to a point. Their *intersection forms a luminous surface* which in optics is called a *caustic.*. The focus of a spherical mirror is the *cusp* of its caustic. The *deviation* of any reflected ray from the *cusp* (or the focus) is called the *aberration* of the ray. The inability of a mirror to collect all the rays to the focus is called the *spherical aberration* of the mirror. This is clearly seen by placing a metallic cup full of milk before a light. The luminous curved surface is then clearly seen on the surface of the milk.

QUESTIONS.

1. What do you understand by "the image of an object?" Enumerate the different kinds of images that can be produced. (2).

2. What is the nature of the image produced in the case of plane mirrors ? (5) Prove this mathematically (4).

3. How can you determine the number of images produced when an object is placed between two mirrors enclosing an angle ? (6).

4. Explain—spherical mirror, the focus, the centre of curvature and the pole (7, 8.)

5. Explain from the 1st law of reflection that light rays reflected from a concave mirror are concentrated to a point (9 or 11.).

6. Trace the successive changes in the nature and position of the image as the luminous object travels from infinite disance up to the mirror (13.)

7. Prove the formula for the concave mirror ; (12) and deduce from it that for the convex one (17).

8. In convex mirrors what is the nature of the foci and the images in all positions of the object ? (15).

9. How are you to determine experimentally the principal focus of the concave and convex mirrors respectively (16).

10. Define : "spherical aberration by reflection" What are *caustics ?* How can it be exhibited (18).

REFRACTION.

1. We have hitherto confined our attention to that portion of the light which rebounds from the reflecting surface. But a portion of the beam also enters into the body, being rapidly *absorbed* when the body is *opaque*, and freely *transmitted* when it is *transparent.*

2. **Refraction** is the *deflection or bending which luminous rays undergo in passing obliquely from one transparent medium into another.* This phenomenon can be easily exhibited by admitting a pencil of the sun's rays into a dark room and receiving it on the surface of water contained in a glass vessel. The *ray must fall obliquely* for if it falls perpendicularly it pursues a straight course through the medium.

3. **Laws of refraction**—(i) *whatever be the obliquity of the incident* ray, the *ratio* which the *sine* of the *incident angle* bears to the *sine* of the *angle of refraction* is *constant for the same two media, but* varies with different media.

(ii) The *incident and the refracted ray are in the same plane, which is perpendicular to the surface separating* the *two media.*

(iii) *When a ray enters into a more refracting medium, it is bent towards the normal; but on entering into a less refracting medium it is bent away from the normal.*

4. **Experimental proof**—Take a vertical graduated metallic disc, at the centre of which a semi cylindrical glass vessel is placed *horizontally,* and filled with water to such a height that the centre of the circle is on the level of the surface of water. Here the surface separating the two media, air and water, is horizontal and the plane of the circle is perpendicular to it. A ray of light is made to pass *along* the *plane* of the circle and fall *obliquely* on the surface of water, it enters into the water and is bent towards the *normal* line (*i.e.* the line perpendicular to the refracting surface) and emerges from water into the same medium. Perpendiculars on the normal line are drawn from the points where the incident and the refracted ray meet the rim of the graduated disc. Now by changing the direction of the incident ray it will always be found that *the ratio of the two perpendiculars is constant, whatever be the incident angle.* If we divide each of these perpendiculars by the radius of the circle, the ratio is *that of the sines of the angles of incidence and refraction.* The *2nd law is also proved by this arrangement,* because the incident and the refracted ray are in the plane of the circle, which is perpendicular to the surface separating the two media.

5. The **index of refraction**—It is the *number expressing the ratio of the sine of the incident angle to that of the refracting angle.* It *varies with* different *bodies. Liquids have greater refracting power than gases,* when a ray enters into a *more refracting* medium, it is *bent towards* the normal, but on entering a *less refracting* medium it is *bent away* from it. As a rule, *refracting power increases with density i.e.,* the *denser* of the two bodies has a *greater refracting* power. But there are *exceptions,* as for instance, the *refracting power of spirit of turpentine* is *greater than* that of *water,* though *water* is *denser.*

If a *ray* pass *through* a *refracting plate* with *parallel faces*, or through a number of plates with parallel faces, *on regaining the medium from which it* started, its *original direction is restored.* This follows from the principle of reversibility.

6. Effects of refraction—(1) *Refraction causes a reservoir of water* to *appear shallower* or a *transparent plate* of any kind *thinner* than it really is. To *demonstrate* this let *a coin* be *placed at the bottom of an opaque vessel*, and let the eye be placed so that the edge of the vessel just intercepts the view of the coin. If now, without altering the position of the observer or the vessel, water be poured into the vessel, the coin will reappear. As there is no change in the position of the eye or of the coin, the rays must have changed their directions. Before water was poured into the vessel, rays came in straight lines, now in passing from water into air, they are bent away from the normal and consequently the rays, that before passed above the observer's head, are bent and directed towards his eye. And as we see the object in the direction in which the light from it enters into the eye, the object now will appear raised from its real position. (2) The same cause makes a *straight stick partly thrust into water* appear *bent* at the *surface away from the perpendicular.* (3) It is owing to refraction that *we can see the stars or sun a little before they are on the horizon* and *a little after they have sunk below it.*

7. Remarks—Reflexion always accompanies refraction; and if one of these disappears, the other will disappear also. A solid body immersed in a liquid having the same refractive index as the solid, vanishes. It will appear as a portion of the liquid itself. In the passage from one medium to another of a different refractive index, light is also reflected, and this reflection may be so often repeated as to render the mixture of transparent bodies practically impervious to light. To this cause is due the *opacity of foam* and *of transparent bodies crushed to powder.* The individual particles transmit light freely, but the reflections at their surfaces are so numerous that the light is wasted before it can reach to any depth in the powder. But if the interstices of the particles be filled with a liquid of the same refractive index, the reflections at these surfaces of the particles are destroyed and the body again becomes transparent. This accounts for *the transparency of the paper soaked in oil.*

8. Total reflexion, critical angle—It has been already stated that a ray of light in passing *from* a denser to a *rarer medium*, as from water to air, is bent away from the normal so that the *refracting angle* is *greater* than the incident angle. By gradually increasing the incident angle in the denser medium, we will arrive at a point for which the *refracting angle* in the air will be 90°, so that the rays will emerge in the direction parallel to the surface separating the two media. After this, refraction ceases; therefore this incident angle is called the critical angle.

Critical angle—*When a ray of light is passing from a denser to a rarer medium* the **critical angle** *is that angle of incidence for which the corresponding angle of refraction is* 90° or It is that *limiting angle of incidence which just allows a ray* travelling *in the denser medium to escape into the rarer one,* so that the *ray* on emergence *just grazes the surface* separating the two media. It is so called because *it marks the limit where the total reflexion begins.* If the incident angle in the medium be greater than the limiting angle, the ray will no longer be *refracted,* but *reflected within* the medium *i.e.,* there will be **internal or total reflexion.**

Total reflection—*It is the reflection of light from the surface of separation of the two media,* when the *ray is in the denser medium and meets the surface at an angle greater than the critical angle.* It is called *total* because in this case, there *is no loss from absorption* or transmission, so that reflexion is nearly perfect.

Conditions necessary for total reflection. (1) The *ray* must *pass from* a *denser to* a *rarer* medium. (2) The *angle of incidence* must *be greater* than *the critical angle.*

9. Critical angle—If μ be the refractive index of the medium.

$$\frac{\text{Sin } i}{\text{Sin } r} = \mu \text{ where } \begin{cases} i = \text{incident angle in air.} \\ r = \text{refracting angle in the medium.} \end{cases}$$

when the ray passes from the medium into air angles are reversed.

Then $\frac{\text{Sin } i}{\text{Sin } r} = \frac{1}{\mu}$. When the incident angle is critical, $r = 90^\circ$.

$\therefore$ Sin $i = \frac{1}{\mu}$ *i.e., sine of the critical angle is the reciprocal of the index of refraction.*

10. Experimental illustration of total reflexion.—Place a coin in a drinking glass, cover it with water to about the depth of an inch and tilt the glass so as to obtain the necessary incident angle at the surface. Looking upwards towards the surface, the image of the coin will be seen shining in that direction.

Experiment to *illustrate the difference between ordinary and total reflection.*

Take a test-tube, containing a little mercury, hold it slantingly in water and look at it from above. The upper part looks as if it were covered with silver. The light which passes through water cannot escape into the air which fills the upper part of the tube, but is totally reflected. The lower part reflects light from the surface of mercury. But this reflection is not so bright as that from the upper portion.

11. Mirage—The *mirage* of the desert and other phantasmal appearances in the atmosphere *are due to total reflexion.* The observer sees in the distance the reflexion of the sky and of terrestrial objects, as in the surface of a calm lake. It is explained by the fact that the sun heats the sands in the deserts, and the layer of air in contact with them becomes lighter than the air above. Up to a certain height, then, from the surface of the ground, the density *increases upwards*, and every layer is more refracting than that below it. A luminous ray from a distant and elevated object *obliquely* traverses the layers which are gradually less refracting. The incident angle gradually increases, until it reaches the critical angle, beyond which internal reflexion takes place. The ray then begins to *rise* in a contrary direction and reaches the eye as if it had proceeded from a point below. The image then appears to be similar to that produced from the surface of water.

A kind of inverted mirage is often seen across masses of calm water, and is called *looming* ; images of distant objects, such as ships and hills, being seen in an inverted position immediately over the objects themselves. The explanation of the *mirage* will apply to this phenomenon also, if we suppose at a certain height, greater than that of the observer's eye a layer of rapid transition from colder and denser air below to warmer and rarer air above.

12. When a luminous pencil traverses a transparent medium, its *deviation depends* upon the *relative positions* of the *bounding surfaces.* The following cases arise. 1st When the *medium is bounded by two parallel planes ;* 2nd. When *it is comprised between two inclined planes* ; 3rd. When it is *bounded by two curved surfaces or a curved and a plane surface.*

13. Media with parallel faces.—It has been already stated that the direction possessed by an oblique ray prior to its meeting a medium of this kind, is restored when it quits that medium. For a ray on entering into a refracting medium receives a push in one direction through a certain angle, during its passage through the medium its course remains unchanged, on emerging again from it, the ray receives the *push* again *through* the *same angle* in the *opposite direction.* Therefore, when the medium is bounded by *parallel* faces, the emergent ray restores the direction of the incident ray *i.e.*, the *emergent* ray becomes *parallel* to the *incident* ray, though *not* in the *same straight line.*

15. Multiple images produced by a glass mirror.—These are readily observed when the image of a candle is looked at *obliquely* in a looking glass. Of the rays which the candle sends to the mirror, some will be reflected from the front, thus giving rise to a feeble image. Another portion will enter the glass, undergo reflection at the back or the metallic surface and emerge after refraction in front, giving rise to a second image (which in this case of silvered mirror is much brighter than the first). This process may be repeated several times, for whenever light is transmitted from one medium to another, only some of the rays get through, the remainder is reflected at the surface which bounds the two media. All the successive images after the first two, continually diminish in brightness.

PRISMS.

16. A **prism** is any *transparent medium* comprised between *two plane faces inclined to each other.* The *refracting angle* of the prism is that enclosed by the two *oblique sides* of the prism. The lines which form the intersections of the faces of the prism are called the *edges*, when *light traverses* a prism *two things happen* ; 1st, it is *refracted* or, deviated from its path ; 2nd if it be a compound light, it is *decomposed* into various kinds of *simple* light, (as for instance Sun's light into *seven* colors) which in optics is called *dispersion.*

17. Path of a ray in a prism.—Suppose a ray enters into a prism of glass. It is refracted towards the normal, let i and r be the incident and refracting angles respectively at the first surface, then here the path of the ray is deviated through the angle $(i-r)$. 'Next when it emerges from the second face of the prism, it is refracted away from the normal, but the two faces are so inclined that deviation in the two cases is in the same direction. Let i' be the angle incident in the air and r', the refracting angle within the prism at the second face, then the deviation here is $(i'-r')$. Then the total deviation of the path of the ray is $D = (i - r + i' - r')$. The *deviation* is always *away from the edge of the prism:* The man who looks through the prism sees the object shifted *towards the edge* of the prism.

$$\text{Now } D = i' + i' - (r + r')$$

But $r + r' = A$, the refracting angle of the prism (Since A I M I$'$ is a quadrilateral figure inscribable in a circle, for each of the angles L A I M and L A I$'$ M is a right angle, therefore $A + M =$ two right angles, but $M + r + r' =$ two right angles $\therefore A = r + r'$)

The *larger the refracting angle, the greater is the deviation.* But with the same prism, the *amount of refraction varies with he direction pursued by the rays through* the prism.

18. Minimum deviation.—The *deviation* produced by a prism *depends* not only upon *its angle* and *refractive index*, but also upon its *position with reference to the direction of the incident ray.* For by turning a vertical prism in front of a ray of light, it can be experimentally proved that the *deviation is minimum when the angle of incidence is equal to the angle of emergence.* It also follows from the law of reversibility and from the experimental fact that for the same prism there is only one angle for minimum deviation. This fact is important, since by means of it the refractive index of a body can be determined. This is the position in which prisms are usually placed in optical experiments. *In* the case of *prisms of small angle* the *deviation* is approximately *proportional to the angle of the prism.*

LENSES.

19. A **lens** is a *refracting medium bounded by two curved surfaces, or by a plane and a curved surface.* If the surfaces be spherical, the lens is called a spherical lens. These lenses possess the property of causing the luminous rays which traverse them, either to *converge* or to *diverge* ; hence they are divided into two principal classes :

1. Converging lenses.

(1) **Double-convex,** with both surfaces convex.

(2) **Plano-convex,** with one surface plane and the other convex.

(3) **concavo-convex,** (meniscus), with a concave and a convex surface, the convex surface being the more strongly curved.

All these are *thicker in the middle than at the edges.*

Their general *effect* is to *render transmitted rays more convergent.* Thus their properties are similar to those of concave mirrors.

2. Diverging lenses.

(1) **Double-concave,** (2) **plano-concave,** (3) **convexo-concave,** in this case the concave surface being the more strongly curved. They are all *thinner in the middle than* near the edges.

20. Definitions—In lenses whose two surfaces are spherical, the centres of these surfaces are called the **centres of curvature**.

The *right line which passes through the two centres* of curvature is the **principal axis**. In a plano-concave or plano-convex lens, the *principal axis* is the *perpendicular* let fall *from* the *centre* of the spherical face *on* the *plane face.*

Optical centre of a lens—It is *the point on the axis of every lens such that, if a ray passes through this point, it* suffers *no angular deviation, so that the emergent ray is parallel to the incident ray.* This point divides the line joining the centres in a fixed ratio. Any ray passing through this point meets the lens at points where its surfaces are parallel, and consequently the lens behaves just as if it were a parallel-sided plate. It *does not coincide with the geometrical centre.* In the case of a meniscus it may be altogether outside the lens.

Any straight line which passes through the optical centre only (without passing through the centre of curvature) is **a secondary axis**.

21. Construction—Like curved mirrors the surfaces of these lenses may be supposed to be made up of an infinity of small plane surfaces or elements; the normal at any point is then the perpendicular to the plane of the corresponding element. Since the elements are inclined towards one another (for the surface is a curved one) the normals meet at a point. (It is an established principle that all the *normals* to the *same* spherical surface pass through its centre.) When a luminous ray then passes through a lens, it really passes through two inclined planes at the points of its incidence and emergence (*i.e.* every element of the lens acts as a prism). Therefore *converging lenses* may be supposed to be *made up of* an *infinite pairs of prisms with their* edges *outwards* and *bases coinciding together.* Similarly *diverging lenses* may be supposed to be composed of infinite *pairs of prisms with their bases outwards and summits inwards.* In order to determine the properties of lenses, it is enough to take one from each group ;—double convex from the first, and double concave from the second.

22. Focus in a double convex lens—1st, *when the luminous point is at an infinite distance,* the *rays* which fall on the lens are *parallel* to its *axis.* All *the rays* in *approaching* the *normal at* the point of *incidence,* and in *diverging* from it *at* the point of *emergence, are twice refracted* towards the axis and *are brought to intersection at a point behind the lens.* This point is the *principal focus* of the lens. As in the case of mirrors the *principal focus* is the focus of parallel rays. The distance of the principal focus or the *focal length* is constant in the same lens but *varies with the radius of the curvature* and *the refractive index.*

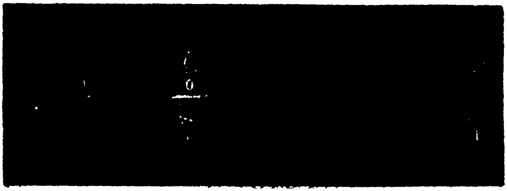
2ndly *if the luminous point is outside the principal focus* and situated at a very great distance from it. All the incident *rays* are divergent and they, after being twice refracted, *on emergence intersect* on the other side of the lens very *near its principal focus.* This point is called the *conjugate focus,* because the luminous point and the focus are exchangeable. As *the point approaches the principal focus,* its *image on the other side retreats from it.* In *these two cases the focus is real.*

3rdly when the point is *at the principal focus,* no *image is formed since* the emergent rays become parallel (*i.e.* the image is formed at an infinite distance).

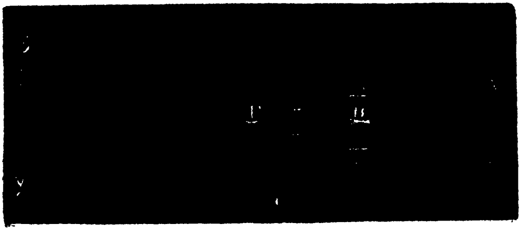
4thly, *when the object is placed between the principal focus and the lens,* the rays after passing through the lens will be *more divergent,* but their prolongations will intersect on *that side* of the lens *on which stands the luminous point.* Here then the focus is *virtual.*

Direction for drawing the diagram—In constructing a diagram, two lines should be drawn from a point representing two rays, one *parallel to the axis* which after refraction will pass through the principal focus, the *other passing through the optic centre,* which after refraction will suffer no deviation. The point of intersection of the line through the principal focus and that through the optic centre will be the position of the image of the point from which lines have been drawn.

23. Images in double convex lenses—If an *object* of sensible dimension be placed *beyond* the *principal focus* and at a *sufficient distance* from it, *i.e.* beyond twice the focal distance, *the image* will be **real, inverted, very near** the principal focus on the other side, (but somewhat farther from the lens than this point) and consequently **very small**. Secondly, if a *very small* object be placed *beyond the principal focus*, but *very near* it *i.e.* between *f* and 2 *f*; the image will be **real, inverted, ve'** **large** and at a great distance. The nearer the object is to the principal focus, the larger is the image. Lastly when the *object is* placed *between* the *principal focus* and *the lens*, the image is **virtual, erect, and larger** than the object.



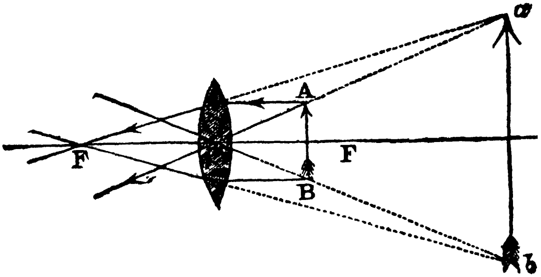
AB = object ; *ab* = image
obj : beyond 2 *f*.



AB = object ; *ab* = image
obj : between *f* and 2 *f*

24. From this it seems that a double convex lens corresponds to a concave mirror. But in the case of the latter the real image is formed on the same side as the luminous point and virtual image on the other side. The reverse is the result in the case of the former ; the positions of the object and the image

are as before mutually convertible. The optical centre in the lens corresponds to the centre of curvature in the mirror, for the rays suffer no deviation when they pass through these points.



AB = object *ab* = image
obj : between *f* and *the lens*

A Relative sizes of object and image—The *magnifying power is greater* in proportion as the lens is *more convex* and the *object nearer* the principal *focus*.

AB = object ; *ab* = image
ABC and *abc* are similar triangles.

$$\therefore \frac{AB}{ab} = \frac{BC}{bc}$$

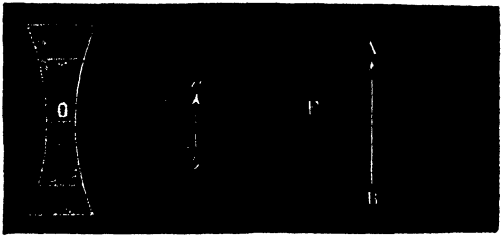
i.e. $\frac{\textit{Linear magnitude of object}}{\textit{Linear magnitude of image}} = \frac{\textit{Dist. of obj. from the optic centre.}}{\textit{Dist. of image from the optic centre.}}$

Experiment—These principles can be experimentally demonstrated by observing the image of a lighted candle placed successively at various distances from a double convex lens.

(b) **Table** *showing the nature, size* and *position* of an *image* in different positions of the object before a converging lens O = object ; I = image ; f = focal length.

Dist. of O.	Dist. of I.	Characteristics of image.
Infinite.	*f*	Real, inverted, diminished.
Greater than 2 *f*	Between *f* and 2 *f*	Real, inverted, diminished.
2 *f*	2 *f*	Real, inverted, of the same size.
Less than 2 *f* (but greater than *f*)	Greater than 2 *f*	Real, inverted, magnified.
f	infinite	No image is seen
Less than *f*	Greater than *f* (on the same side as object.)	Virtual, erect, magnified.

25. Foci and Images in a double concave lens—In double concave lenses there are *only virtual foci,* whatever the



AB = object ; *ab* = image.
Object between F and the lens

distance of the object. The rays after traversing the lens become *divergent* and only the prolongations of these rays meet one another in a point. Like *convex mirrors* they only give *virtual* images. Hence whatever the distance of the object, the image is always *virtual, erect, and smaller than the object.*

26. The determination of the principal focus—The principal focus of a convex lens is determined by exposing it to the sun's rays so that they are parallel to its axis. The point on which the emergent rays meet on the other side is the principal focus. *Another method* is to place the lens between a luminous body and a screen, then to *adjust its position* in *such* a manner *that the image is equidistant with the object.* The *focal length* is then *one-fourth of the distance between the object and the image.* In a concave lens the arrangements are the same as in convex mirrors. There are *spherical aberration* and *caustics by refraction* in lenses.

27. Application—When sun's rays are received on a condensing lens or a concave mirror not only light is concentrated but *heat* also, for a peice of an inflammable body (phosphorus) placed there takes fire. So *guns can be fired by* concentrating the *sun's rays* (by means of a lens) on the touch-hole. This property is utilised for producing fire in burning glasses. In *light houses* the application is made of the principle that any light placed at the principal focus of a very powerful lens sends rays (after refraction through the lens) in a parallel direction, so that light can traverse a very great distance without any perceptible loss. In order to make the lens very powerful, it is made up of parts of several lenses.

28. Formula for the lens—Let Q be the origin of the pencil, whose axis Q A B passes through the lens, the thickness of which may be neglected ; Q R any ray incident at R in the first surface, and refracted in a direction which cuts Q A in F_1 ; O, the centre of the sphere. Then F_1 is the geometrical focus of the pencil after one refraction. Let F be the focus of the pencil at emergence, A Q $=u$; B F $=v$; r, and s, the radii of the 1st and 2nd surfaces respecly ; join O R from the refraction at the 1st surface we get.

$$\mu=\frac{\text{Sin } QRO}{\text{Sin } F_1RO}=\frac{\text{Sin } QRO}{\text{Sin } ROQ}\cdot\frac{\text{Sin } ROF_1}{\text{Sin } F_1RO}$$

$$=\frac{QO}{RQ}\cdot\frac{RF_1}{OF_1}$$

In the limit $\mu = \frac{QO}{AQ} \cdot \frac{AF_1}{OF_1}$

or $\mu . u\,(AF_1 - r) = (u - r)\,AF_1$

Dividing each by u. r. AF$_1$ $\therefore \mu \left(\frac{1}{r} - \frac{1}{AF_1}\right) = \frac{1}{r} - \frac{1}{u}$

$$\text{or} \quad \frac{\mu}{AF_1} - \frac{1}{u} = \frac{\mu - 1}{r} \qquad (1)$$

Refraction at the 2nd surface—Now since the law of reversion is true we can assume that a pencil converging to F would have F_1 for its focus after refraction at B in the 2nd surface. Therefore from (1) we get.

$$\frac{\mu}{BF_1} - \frac{1}{v} = \frac{\mu - 1}{s}$$

If the thickness be neglected $BF_1 = AF_1$ we get

$$\frac{1}{v} - \frac{1}{u} = (\mu - 1)\left(\frac{1}{r} - \frac{1}{s}\right)$$

From this formula we can get the formula for other lenses by making necessary changes in the signs (see the formula for the curved mirrors).

QUESTIONS.

1. What is refraction ? On what condition does it take place ? (2) What are the laws of refraction ? (3) Experimentally demonstrate them (4)

2. What is "Index of Refraction" ? How does it vary in different bodies ? (5) When a ray enters into a medium with parallel faces, does any change take place in its direction ? (5) What are the effects of refraction ? (6) Why does the bottom of a shallow pond appear shallower ? Explain the apparent bending of a stick when a part of it is immersed in water. (6)

3. Under what circumstances would a colourless mineral be invisible in a liquid ? (7) Account for the transparency of the paper soaked in oil. (7)

4. Define : Total Reflection and critical angle. Why is the former called *total* (8) Prove that the sine of the critical angle is the reciprocal of the index of refraction. (9) How can the total reflection be experimentally demonstrated (10) How would you illustrate by experiment the difference between ordinary and total reflection ? (10)

5. Explain the "mirage" of the desert and the "looming" of the ship in a calm weather at sea. (11)

6. When a ray enters into a medium with parallel faces, its direction remains unchanged. Prove this. (13) Why does a glass mirror produce a succession of images ? (15)

7. Define a prism. (16) Trace the path of a ray in a prism and calculate the amount of its deviation. (17)

8. How can you determine that the deviation is least when the incident angle is *equal* to the emergent angle ? (18)

9. What is a lens? Mention the two principal classes in which lenses are divided (19)

10. Define:—Principal axis and optical centre. What is the peculiar property possessed by the latter? (20)

11. Explain the construction of a lens as a refracting medium (21)

12. Trace the changes in the position of the foci and images in different positions of the luminous point; 1st in a double convex lens (22, 23) 2nd in a double concave lens (25) On what does the magnifying power of a convex lens depend? (24)

13. How are you to determine experimentally the principal focus of a convex or a concave lens. (26)

14. Explain how the converging property of the lens has been applied to practice especially in light-houses. (27)

15. Establish the formula for the lens. (28)

OPTICAL INSTRUMENTS.

1. By the term *optical instrument* is meant any combination of lenses or of lenses and mirrors. By its means the limits of vision have been enormously increased, either by *magnifying* the dimensions of objects that are too *minute* to be seen by the naked eye; or by bringing within sight, things that are too *far* to be distinctly seen by the naked eye. These instruments then are chiefly divided into two classes; (1) **Microscopes,** which are designed to *magnify* the dimensions of minute objects; (2) **telescopes,** which bring within our vision very distant objects, whether terrestrial or celestial. Besides these there is a *third class* of instruments used to project on a screen, the magnified or diminished image of an obect. The *two former* classes *yield virtual images,* and the last, with the exception of one, *yields real images.*

2. General composition of telescopes.—The first two groups of instruments consist essentially of two individual or groups of lenses. The *one which receives the light from the object* and concentrates it in a focus, (where in the case of telescope it gives a small image), is called the *field-glass* or the *objective.* The other which acts as a magnifying glass, *is placed near the eye and serves to view the image formed by the object glass* is called the *eye-piece.* These are mounted in long metal tubes sliding into one another (so that the glasses may be brought to the proper distance) and blackened on the inside to absorb the oblique rays.

In reflecting telescopes *concave mirror* is used instead of the object-glass. Instead of a single lens, a group consisting of two or three, is often used to avoid chromatic and spherical aberrations (*i.e.* to give a colourless and sharp image) and to obtain a greater magnifying power.

3. Telescopes.—They are of two kinds : **astronomical** *used to observe celestial objects*, and **terrestrial** by which *distant objects on earth* are observed. An *astronomical telescope* consists essentially of two convex lenses, one of which gives a real and inverted image of the object, which is looked at through the other, which also magnifies the object.

The *object-glass* which is always of a very great focal length, *forms the inverted image of a distant celestial object at its principal focus*, (since the rays which enter the glass are parallel.) This image is looked at through the *eye-piece*, which gives a *virtual*, *erect* and *magnified* image of the *first* image. The eyepiece is so placed that the *first image* formed by the object glass *is situated* between it and its principal focus. Thus the observer sees *a reversed and greatly magnified image of the object.*

M = object-glass ; N = eyepiece AB = object (at a very great distance so that the rays are parallel). ab = 1st image (at the principal focus of M ; a' b' = image (seen by the observer.)

The *magnifying power* of a telescope is greater, the *greater* the *diameter of the object-glass* and *less its convexity*, and the *more convex is the eyepiece.*

4. Mechanical arrangements.—The object glass is set in a mounting which is screwed into one end of a strong brass tube. In the other end slides a smaller tube containing the eyepiece ; and by turning the milled head, in one direction or other, the *eyepiece* is moved forwards or backwards.

Focussing the instrument.—As bodies are situated at different distances, their images occupy different positions. Therefore in each case, the *eyepiece is to* be **pulled out** *or* **pushed in,** in order to *bring the image between the eyepiece and its principal focus*, and *in* such *a position that* the ultimate image *is* seen *at the distance of distinct vision of the observer.* This operation is called **focussing.**

5. Microscopes—These instruments enable us to observe objects which are too small to be seen by the naked eye. They are of two kinds *simple* and *compound.*

6. Simple microscope.—By this is usually meant a *lens* of *short* focal length mounted in a manner convenient for the examination of small objects, *i.e.*, the lens is mounted on a stand and can be raised or lowered by a screw acting on a rack. The *object to* be observed *is* then *placed between the lens and its principal focus.* The magnifying power is greater, the *more condensing* is the lens. This lens is frequently used by watchmakers and engravers.

7. Compound microscope—It is so called since it is made up of several lenses. In this there is one lens or a group, called the *object-glass*, which gives a *real*, *inverted* and *greatly enlarged image* of the object ; and this *image* is itself *again magnified* by viewing through *another lens* or a group, called the *eye-piece*.. The *object* is placed on a support called the *stage*, at a distance only *slightly exceeding* the focal length of object-glass. The eye-piece is at such a distance that the image produced by the object glass, is situated between it and its principal focus. The observer looking through the eye-piece sees a *virtual* and magnified *image* of the first image. By a compound microscope *the object is magnified by both the glasses.* The *magnification depends more* especially *on the object-glass.* In order to illumine the object a concave mirror is placed beneath the object, which concentrates upon it a large quantity of light.

M = object-glass ; N = eyepiece ; E = the eye ; AB = object (placed beyond *f* but very near it ; *ab* = 1st image thrown by M, larger) ; *a' b'* = image as seen by the observer.

QUESTIONS.

1. Define an optical instrument (1) what is its general composition ? (2)

2. Explain the principle on which astronomical telescopes are constructed (3). Describe the construction and mechanical arrangements of a telescope—(3. 4.) what is meant by focussing a telescope? (4)

3. Describe the arrangements of glasses in a compound microscope—(7.)

8. **Eye as an optical instrument.**—It is clear from the above description that the eye serves as a camera obscura of which the pupil is the aperture, the crystalline is the condensing lens and the retina is the screen or the sensitised paper on which the image is produced. A pencil of rays entering the eye from an external object will undergo a series of refraction first, at the anterior surface or the cornea, then in the crystalline and the posterior chamber, all tending to make the rays convergent. A *real* and *inverted* image is thus formed of the external object to which the eye is directed. If it falls *on* the *retina* the object is distinctly seen; if not, the eye will have to be *adapted* to make the image fall on the retina. Many theories have been advanced to explain how it is that we see the object in its erect position though the image falls inverted; but the subject is still open to discussion.

9. **Persistence of impression on the retina.**—The impressions of images on the retina remain for some time after the object which has produced them has disappeared. If a piece of glowing charcoal is rapidly rotated, the appearance of a circle of fire is produced. This is owing to the fact that the impression produced by the charcoal in the first time remains on the retina when the point again reaches that place. Several interesting magical toys, such as *magical disc*, *deceiving disc* &c, are constructed on this principle of persistence of impression on the retina.

DISPERSION.

1. **Dispersion** is the *decomposition of any compound light into several kinds of simple light by passing it through a prism.* Newton first decomposed solar light by allowing it into a dark room through an aperture and placing horizontally in its passage a glass prism. The beam on emerging from the prism is not only refracted towards the base but instead of a colourless image of the sun, a *band* is seen rounded at the edge and coloured in all the tints of the rainbow. A **spectrum** is *the luminous image formed when a beam of white light is thus decomposed by a prism.* If *the light used be that of the sun, the image is called the* **solar spectrum**. The solar spectrum then consists of an infinite number of colours of which the seven following are distinguishable; *Violet*, *indigo*, *blue*, *green*, *yellow*, *orange* and *red.*

2. **The explanation of dispersion.**—The wave of ether

generated by luminous bodies are not all of the same length ; some are longer than others. In refracting substances the *short waves are more retarded than the long ones ;* hence the short waves are more refracted than the long ones. This is the cause of dispersion. *Each colour is then due to a certain wave length of the ether vibration* and as the velocity of light is the same in each case, each *colour depends upon the number of ether waves striking the eye* in a second.

3. Newton's experiments.—The colours of the solar spectrum are *simple* because if all the colours are intercepted by a screen except one, and that one allowed to pass through a second prism, it will be refracted without decomposition. This is observed with every colour of the spectrum and so these colours are called primary colours. From the experiment on solar spectrum Newton concluded that the sun's light is composed of seven distinct colours, which united give the impression of *white*, while, when separated, each produces its own impression.

That white light is composed of seven colours *may be further demonstrated by* combining them so as to produce white light again. This may be done in several ways. If a double convex lens or a concave mirror be placed in the path of a solar spectrum these several colours will combine in the *focus* where the *white* image is seen. The same thing may be proved by **Newton's disc**.

Newton's disc—It consists of a card-board disc in which are pasted strips of papers (sectors) of the colours of the spectrum. The colours are arranged exactly in the same dimensions and order as those of the spectrum. When the disc is rapidly rotated it appears white. It is due to the fact that the impression produced upon the eye by any body remains for some time after the cause which produced it vanishes. Thus when the disc is *rapidly* rotated, the impression of seven colours is simultaneous (*i.e.* when the last colour affects the eye, the impressions of the first six colours have not passed away, and so the eye seems to be affected by all together and the disc appears white.

4. Luminous, heating and chemical effects of the spectrum.—The several rays of the spectrum differ not only in their colour but also *in* their illuminating power, in the heat which is observed in them and in the chemical effects which they produce. The *brightness is greatest in the yellow*, orange, and green, and falls off gradually on both sides.

The *heating effect* upon a thermopile placed in the spectrum continues to increase in going from the violet to the red and *attains its greatest intensity beyond the visible spectrum at the red end.* Herschel proved the existence of these ultra-red rays which are less refrangible and so they are called **Herschelian** rays.

The *chemical effect* produced upon a sensitized paper or any vegetable colour placed in the spectrum *is very feeble in the red,* strong in blue, and violet and is *sensible to a great distance beyond the violet.* These rays are more refrangible than the spectral rays and are also called **actinic** rays.

5. Dark lines of the spectrum.—When a pure solar spectrum is observed by admitting a pencil of rays into a dark room through a narrow slit and looking at this slit through a prism with its edge parallel to that of the slit, numerous dark lines are seen, forming as it were the dark images of the slit. Each of these lines is an indication, that particular kind of illumating ray is wanting in the solar light. Every elementary ray that is present gives the image of the slit in its own peculiar colour, and these images are arranged in strict contiguity so as to form a continuous band of light passing by easy and gradual transition through the whole range of simple colours, except at the narrow intervals occupied by the dark lines. These dark lines are characteristic of solar light only, for if the slit is illuminated by any other light, such lines are not seen, or their number or relative positions vary. In the case of electric light bright lines are seen in place of dark ones. In flames coloured by chemical bodies these dark lines are replaced by brilliant lines of light which differ in different bodies. Fraunhofer first mapped these dark lines and so they are called **Fraunhofer's lines.**

6. Spectroscope.—This name is given to the apparatus used for the study of the *spectrum.* It consists of a telescope and two other tubes containing converging lenses. They are mounted on a horizontal table and are so inclined that the axes of the three converge to a prism placed between them. The substance to be examined is burnt in front of one of these tubes the flame passes through the slit at the end of the tube and after traversing the lenses they form a parallel pencil of rays which falls on the prism. Here they are refracted and *dispersed* and the spectrum is produced. The observer looking through the telescope sees a real and inverted image of the spectrum. The other tube contains a scale. The rays of light proceding from this scale and lighted by homogeneous light are also refracted by the prism and the observer seeing the spectrum and the scale at the same time easily determines the relative distance of the several lines.

7. Spectrum analysis.—Metals and their compounds impart to flame peculiar colours which are characteristic of them These colours are due to the vapours of the metals ignited. When these vapours are examined by the spectroscope, instead of giving *continuons* spectrum (*i.e.* one color passing into and other) they produce bands of colour separated from each other by dark lines. When minutely observed each coloured band appears to be made up of a group of bands with fine dark lines. The position of these bands is the same for the same metal. If two or three metals be introduced into the flame at the same time the bands of *each* metal are present in the spectrum as if others were not there. The constituent metals of any compound will give each its characteristic bands ; so if new bands are present in the spectrum it can be easily said that a new metal is present. *By this method* of spectrum analysis many new metals, such as, *Cæsium*, *Rubidium*, *Thallium*, *Indium*, *have been discovered.*

QUESTIONS.

1. What is *dispersion* ? (1) How can you explain it from the wave theory of light ? (2)

2. Describe the experiments to prove that the colours of the spectrum are simple. (3) How can you prove the heating and chemical effects of the solar spectrum ? (4)

3. Describe the instrument called "spectroscope" (6) and the process called the "spectrum analysis" (7) What are *Fraunhofer's lines* ? (5)

MAGNETISM.

1. Properties of magnets—Natural and artificial— Magnetism is the name given to another mysterious power in nature, which man has enlisted in his service and rendered subservient to his purposes. This word is derived from the name *magnet* that was given by the ancients to a mineral having the composition Fe_3O_4 (oxide of iron), which was first found at *Magnesia* in Asia Minor. This mineral called the **natural magnet** has the property of *attracting iron and a few other metals,* (Cobalt and nickel &c). It also *points north and south when suspended by a thread or placed on a pivot.* This property was turned to advantage in navigation, and from that time magnet received the name of *lodestone.*

It is also endowed with the *property of communicating its own virtue to iron or steel.* If a piece of iron, or better, a piece of steel be rubbed against it, it is found to have acquired the properties of the magnet. Such magnets are called **artificial magnets** for they are produced by art. They have all the properties of natural ones and are *more powerful and convenient, for they may* be made into *any shape.*

Nowadays **Electromagnets** are used instead of ordinary artificial magnets, (called also **permanent magnets** since they retrain their properties for a long time.) They have certain advantages over the permanent magnet, for their strengths may be changed at will, or they may be reduced to the neutral condition very easily ; this cannot be done in the case of permanent magnets : They consist of soft iron rods placed within a coil of insulated copper wires. When a current is sent into the coil, it is converted into a magnet. Its strength depends upon strength of the current and upon the number of turns in the coil.

Dr. Gilbert discovered another property of a magnet viz that *the attractive power of a magnet is greatest at the two ends. It decreases rapidly as one approaches towards the middle, where there is no attraction at all* in other words *it has two poles and a neutral line.*

2. Definitions.—A **magnetic needle** is a thin lozenge-shaped bit of steel with a metal cap in the centre, so that it can rest on a pivot and oscillate freely.

The **poles** of a magnet are the points generally near the ends of a magnet where attraction or repulsion is greatest.

The **axis** of a magnet is the imaginary line joining the two poles.

The **neutral line or the magnetic equator** is the imaginary line perpendicular to the axis, drawn through the point where the magnetic force is zero.

The *action* of *magnets* upon iron, and other magnetic bodies *is also exerted through bodies that are not magnetic.* If a magnet is placed on a table and a paper placed over it, iron filings sprinkled over the paper will arrange themselves round the poles and form curved lines from pole to pole.

3. Magnetic attraction and repulsion.—If the *two poles* of a bar magnet be successively brought *near* the *same* pole of a magnetic needle *one* pole of the magnet will *attract* the needle and *the other repel* it. There are therefore *two opposite kinds of* magnetic *poles*, whose action however on magnetic bodies is the same. If the *poles* of two magnetic needles, *which* are *both attracted by* the *same* pole of a magnet, *be brought near*, they *repel* each other ; while the needle *point attracted* by a pole of the magnet, *brought near* another needle *point repelled* by the *same* pole, will *attract each other.*

Laws—(1) *Like magnetic poles repel one another, and unlike poles attract* one another.

(2) The *force varies directly as the product of the two quantities of magnetism, and inversely as the square of the distance between them.*

4. Experiment to show the opposite actions of the north and south poles.—If over the pole of a bar magnet supporting a piece of iron, a contrary pole of another magnet of same dimension be placed, the iron piece will fall down, because the two magnetic forces at the poles will neutralize one another and there will be no action on the magnetic body.

It is clear from what is stated above that every magnet has got two poles and a neutral line. It is impossible to get a magnet with one pole. If we take a magnetic needle with two poles and break it into two parts, each part will have two opposite poles and a neutral line.

The force exerted by a magnet on any magnetic substance or on another magnet, called the *magnetic force*, is greater the less the distance between the two bodies.

This force is also *mutual* (*i.e.* both the magnet, and the magnetic body attract one another), for not only does a magnet attract bits of iron but magnetic needles a e also observed to be drawn towards a lump of iron.

The *strength of a magnet is the strength of its poles, i.e.* the magnetic force which they exert.

5. Distinction between magnets and magnetic bodies.—(1) A *magnet has two poles and a neutral line,* so that the force it exerts on any magnetic body is manifested near the ends and there is no force in the middle. But a *magnetic body exhibits no* such *polarity,* a magnetic needle brought near it will be attracted no matter at which part the needle is placed.

(2) A *magnetic body attracts both the poles of* a magnet whereas a *magnet attracts one pole and repels the other.*

(3) When *a magnet* is *suspended* by means of a thread it *places itself north and south,* but when a *magnetic body* is suspended in the same manner, it *remains in any position.* In magnets the two magnetisms in each molecule are separated and each produces a separate effect, while in magnetic bodies the two magnetisms are combined and produce no effect.

6. Magnetic Induction.—It is the *influence* in virtue *of which a magnet can develop magnetism in magnetic bodies.* It can take place *with or without actual contact* between the magnet and the magnetic body. When a magnetic body (such as iron) is placed in contact with the pole of a magnet the former is converted into a magnet, for another bit of iron may then be hung to it and so on. But if the iron bit be removed from the top of the chain the rest will drop down and will be found to be no longer magnetic. The *explanation* of this *is* that the pole separates the two kinds of magnetism (originally in the neutral state) in the magnetic body, attracting the opposite kind and repelling the similar. Thus the first bit of iron is converted into a magnet. This again separates the magnetisms in the second bit, attracting the opposite and repelling the similar, and so on. But when the first bit is removed the separated magnetisms of the other bits immediately combine together, and they no longer exhibit magnetic properties. In *this case there is actual contact* between the magnet and iron.

To show that magnetic *induction* can take place *without actual contact,* a bar of soft iron is held near some iron filings If now a magnet be brought near the other end of the iron bar.

the iron filings will be seen to be attracted by the bar. This proves that the presence of the magnet has *induced* magnetism in the bar.

7. **Coercion or Retentivity of magnetic force.**—It is the power in a magnetic body of resisting magnetisation or demagnetisation, *i.e.*, it offers resistance to the separation of two magnetisms, but it also prevents their recombination when once they are separated. This force varies with different bodies and therefore we see that all magnetic bodies cannot become magnets permanently. *Steel*, *nickel*, cobalt, &c, *acquire* magnetic properties *slowly* but *retain* them *permanently*, whereas *soft iron acquires* it *quickly* and *loses it soon*. *Twisting* or *hammering imparts* to iron or steel a considerable *coercive* force, but the most powerful of these influences is the operation of *tempering*.

8. **Magnetisation.**—A magnetic body may be magnetised (1) by simply rubbing it with a magnet ; (2) (where no other permanent magnet is available) by simply placing the body in the magnetic meridian for some time ; (3) by heating a steel bar to redness or cooling it, slowly or suddenly, while in the magnetic meridian ; (4) by passing electric current through the coil round the iron bar. A magnet loses its magnetism partially or wholly if hit or knocked about or twisted or heated to redness.

9. **The earth as a magnet.**—It has been found that when a magnetic needle is placed on a pivot on which it can turn freely it ultimately sets in a position more or less north and south. If removed from this position it always returns to it after a certain number of oscillations. If this needle is placed on a floating cork it will be observed that the needle sets in a certain direction but does not proceed either towards the north or south.

The first experiment *proves* that a certain force is exerted by the earth upon the needle along north and south, and *the second shows* that this force is simply **directive**. *The magnetic action of the earth on a* magnetised *needle may be compared to a couple*, for the north pole of the earth attracts the north pole of the magnetic needle, and repels the south pole with the forces that are equal, parallel, and unlike. This is owing to the great distance of the poles of the earth from one another, and also from from those of the magnetic needle which is very small. The south pole of the earth acts similarly on the poles of the needle, and produces two other forces which are also equal, parallel and unlike. Thus there are now two forces acting on each of the poles which may be reduced to a single resultant. These two resultant forces acting on the two poles of the magnet are equal, parallel, and act in opposite directions, and so they constitute the *terrestrial magnetic couple.*

Observations made on the different parts of the earth prove that the earth has magnetism it. It may be regarded as a huge magnet whose poles very nearly coincide with the geographical poles. The pole of a magnetic needle, which points towards the *north*, is called the *north* pole and that pointing towards the *south*, is the *south* pole. As the north pole of the needle is directed towards the north, it is evident from the law of magnetism, that *the magnetic condition of the northern region must be opposite to that of the north end of the needle.*

10. Declination.—When a magnetic needle points towards the north an imaginary plane passing through its two poles is called the **magnetic meridian** of the place. It does not coincide with the geographical meridian. The angle which the magnetic needle makes with the geographical meridian of the place is called the **Declination** of the place. The declination *varies in different places* and is said to be *east* or *west*, according as the north pole of the needle is to the east or west of the geographical meridian. Even *in the same place there are annual* and *diurnal* variations in the declination. Besides these and the *secular* changes (*i.e.*, those that require many years to run their course) the magnetic needle undergoes accidental variations called *magnetic storms* or *perturbations.* The latter frequently occur when an Aurora is visible and also when thunderstorms and volcanic eruptions take place.

11. Physical theories.—When a magnet is broken into two parts each part is a complete magnet, possessing poles and a neutral line, its magnetism is nearly the same as that of the original magnet. If the broken parts be closely joined together the adjacent poles neutralize one another, and disappear leaving only the poles at the ends as before. If a magnet be ground to powder each fragment will still act as a little magnet and exhibit polarity. It appears therefore that *every particle of a magnet is itself a magnet*, but the particles are so arranged that their like poles all face one way. *This* may be *demonstrated* by taking a glass tube filled with iron filings and bringing a magnet near it. As soon as these particles are converted into magnets they arrange themselves endways.

12. Mariner's compass.—This is a declination compass used in guiding the course of a ship. It consists of a cylindrical case which is supported on *gimbals*, to keep the compass in a horizontal position in spite of the rolling of the vessel. *Gimbals* consists of two concentric rings one of which is attached to the case itself and moves about an axis. This axis plays in the outer ring which moves about another axis, fixed to the support, at right angles to the first. In the bottom of the box is a pivot on which is placed the needle of the compass. On the needle is fixed a mica disc whose diameter is a little larger than the length of the needle. On the disc is traced a star or rose with thirty-two branches. This swings round with the needle so that the point marked N on the disc always points to the north.

13. Theories of magnetism.—The most prevalent of the theories brought forward to explain the magnetic phenomena is the **two-fluid-theory.** It assumes that all magnetic bodies possess two kinds of magnetic fluids, each of which acts repulsively on itself but attracts the other fluid. Before magnetisation these fluids remain combined round each molecule and mutually neutralize each other. They can be separated by a greater force than their mutual attraction, when they arrange themselves in a certain position about the molecules of the body, but they cannot be removed from the body.

14. Objections to the theories.—It has however been established beyond dispute that magnetism is not a fluid, but the term is still in use because we see that under certain circumstances magnetism distributes itself in magnetic bodies in the same manner as an elastic fluid would do. When a magnet is rubbed upon a piece of steel it magnetises the steel without losing its own magnetism, a fluid cannot propagate itself indefinitely without any loss. Again when a magnet is broken into several parts, the magnetism of each part is nearly the same as that of original magnet. If it were a fluid the magnetism of every part must have been less than that of the whole magnet and also the sum of the magnetisms of the parts must have been equal to that of the whole. Experiments on mechanical, optical and other effects of magnetism and also the close connection between magnetism and electricity prove that it is not a fluid. The modern theory holds that magnetism results from certain properties of ether of space and that in every magnetic field there is a whirling motion of ether particles along the lines of magnetic induction, which produces tensions along the lines of force and pressures across them.

Surface distribution of magnetism in some cases is proved by placing a magnetic needle in an acid when the surface layer is removed by the acid no trace of magnetism remains. Again in a bundle of magetic needles those on the surface appear to be magnetised.

QUESTIONS.

1. Define—magnetic equator, and pole (2). Demonstrate experimentally the opposite actions of the poles. (4) Distinguish a magnet from a magnetic body (5). What is 'magnetic induction' and how can this be proved where there is no contact between the magnet and the magnetic body ? (6).

2. Define "coercive force" (7). What are the different methods of magnetisation ? (3). Describe the experiment which proves that the earth is a magnet exerting *directive* force on the magnetic needle (6). Describe " mariner's compass". (12). What do you understand by " the declination of a place ? (10).

3. State fully the hypothesis brought forward to explain magnetic phenomena (13). Prove that every particle of a magnet possesses polarity (11).

FRICTIONAL ELECTRICITY.

1. The term electricity is derived from a Greek word *electron* meaning *amber*, for it was known to ancient Greeks that *amber* and *jet* when rubbed possess the power of attracting light bodies, though it has been subsequently observed by Gilbert that almost *all bodies possess this power.* It remains latent in bodies but it can be evoked in them by friction, pressure, cleavage percussion, chemical action, heat, and magnetism ; and it manifests itself chiefly by attraction and repulsion by heat and light, by shocks, and chemical decomposition.

2. **Sources of electricity.**—The causes which develop electricity in bodies may be divided into three groups.

I. Mechanical sources such as friction, pressure, and cleavage. By rubbing a glass rod against silk the rod is observed to attract pithballs or paper bits owing to the electricity produced. If a plate of mica be rapidly split in the dark a faint light due to the electricity produced is perceived.

II. Physical sources.—Such as *variations in temperature.* In many minerals especially in *tourmaline* electrical properties are observed when they are either heated or cooled.

III. Chemical sources.—They are chemical combinations and decompositions. When elements combine together to form compounds and also when compounds are separated into elements, electricity is developed.

3. **Electrical attraction.**—When a glass rod is rubbed with silk and brought near a pithball hung by a fine thread from

a support, the pithball is attracted towards it. This shows that *an electrified body attracts an unelectrified* one. This electrical attraction is *mutual*, for if an electrified body be suspended by a thread, and an unelectrified body be brought near it, the former will be attracted towards the latter.

It is also observed that if *the part* of the rod that is *not rubbed be presented to the pithball*, the *latter is not at all affected.* This shows that the electricity that is developed in one portion, has not been transmitted to the other portion. Therefore the *body is* a *non conductor of* electricity.

It can also be proved that both *the rubber* and the *thing rubbed are* in an *electrified* state *for both will attract the pithball.*

A large number of the bodies especially all the metals when *held in the hand* and rubbed exhibit no sign of electrification. They are termed *non-electrics*, but the term is erroneously applied, for if they are fastened to glass handles and then rubbed with silk, they behave like electrics. It is observed that *in these bodies electricity that is developed in one portion is distributed over the whole surface. This proves that these* bodies are *conductors* and consequently when they were held by the hand and rubbed electricity was developed, but it was conducted away ; therefore they did not show any sign of electrification.

4. Electrical repulsion.—If an *electrified* glass rod be held near a pith-ball the latter will be attracted by the rod, stick to it and a moment after will be repelled from it. Now an *unelectrified* body brought near this pith-ball will be seen to attract it. This proves that the pith-balls has been electrified by coming in contact with the electrified rod. It appears then that the *repulsion* of the pith-balls from the *electrified* glass rod was *due to* their being *charged with similar* or like *electricities.* This may also be shown in the following way. If two pith balls are suspended by two threads from the same point of a stand and if they are touched by an electrified body, these balls being electrified with the same electricity will be seen to repel one another.

Two kinds of electricity—A *pith-ball*, though *repelled by* an electrified *glass rod*, when charged with the same kind of electricity, will be *attracted by* a rubbed *sealing wax*,presented to it. Similarly a pithball electrified by the rubbed sealing wax will be repelled by the latter,but will be attracted by the rubbed glass rod. These experiments prove that **there are two kinds of electricities ;** *the one* developed *by the fraction of glass with silk* called the **vitreous,** and the *other by the friction of resin with fiannel* called the **resinous** electricity, and that *like electrified bodies repel one another* and *unlike electrified bodies attract* one another.

5. The *kind of electricity* produced is however found to *depend* not only *on the thing rubbed* but *also on the rubber,* for glass yields *resinous* electricity when rubbed with skin, and resin yields vitreous electricity if rubbed with an amalgam of tin and mercury spread on the leather. The nature of electricity developed by friction depends also on the *degree of polish,* the *direction of friction* and *the temperature.* If two pieces of the same body, but of different degrees of polish, or of different temperatures be rubbed together, that which is least polished or most heated is negatively electrified. *Generally* speaking *particles which are most readily displaced are negatively electrified.* In the following list each body becomes positively electrified when rubbed with any of the bodies following it, but negatively when rubbed with any of those that precede it.

Catskin
Flannel
Glass
Silk
The Hand
Wool
Metals
Caoutchouc
Resin
Sulphur
Gutta Percha
Gun Cotton

Separation of electricities—When a separation of electricities takes place by friction or any other means, the *amounts* of *vitreous* and *resinous* electricities produced are always *equal,* so that on being united they exactly neutralize each other. *This* is clearly *shown* in any form of electrical machine in which the opposite poles are connected. For, unless it were true one pole would on working the machine still acquire a charge of electricity. *Another proof* that these amounts are equal is that if two bodies are rubbed together and the electricities both of the rubber and of the rubbed be imparted to a third body,it will show no sign of electrification at all. The vitreous electricity is changed by the addition of resinous electricity, just as if a negative number were added to a positive. For this reason the former (*i.e.,* vitreous) is called the *positive,* and the latter (*i.e.,* resinous) the *negative* electricity. Franklin first introduced these terms.

6. Theories of Electricity.—Various theories have been advanced to explain these phenomena but all are more or less unsatisfactory. The most convenient is the **two-fluid-theory** of Symmer. He assumes that *every body contains an indefinite quantity of* a subtle imponderable fluid called the *electric fluid. This* fluid again *is composed of two fluids called the positive* and the *negative*, which *neutralize one another* when they exist combined (since the quantities are equal) and then the body is said to be *in the natural* or neutral *state.* When by friction, chemical action and other means this condition is disturbed, the two fluids are separated and the electrified body gains an additional quantity of the one fluid and loses an equal quantity of the other. It is clear from the theory that one of the fluids can never be excited without a simultaneous production of the other. This theory has been modified by Franklin who maintained the **one-fluid-theory.**

According to this theory there is a *single* fluid, distributed usually uniformly in all bodies. All unelectrified bodies possess it in a *certain normal amount.* When they are subjected to friction the fluid distributes itself *unequally* between the rubber and the thing rubbed, one having *more* of the fluid, the other *less*, than the *normal* amount. The body which is supposed to have an *excess* being said to be *positively* electrified, while that which has *less*, *negatively* electrified; the particles of this fluid repel one another and attract particles of other kinds of matter. In completing this theory Epinus introduced the additional hypothesis that particles of matter repel one another. But to reconcile this to the theory of gravitation, he supposed that the attraction between the electric fluid and matter is greater than the .self-repulsion of each.

Objections.—It is however quite certain that electricity is not a material fluid, for though it resembles a fluid in its property of apparently flowing from one point to another, it differs from every known fluid, inasmuch as it has no weight and possesses self-repulsion.

Another theory commonly known as the *molecular theory* supposes that electrical states are the results of certain peculiar conditions of the molecules of the bodies or of the ether surrounding the molecules. Faraday held this theory. There is much to be said in favour of it.

7. Definitions.—An **electroscope** is an instrument used to detect the presence of electricity in a body; that commonly used, is the *electric pendulum*, consisting of a pithball suspended by a silk thread from a stand.

The quantity of electricity of either kind produced, by friction or other means, upon the surface of a body is called its **charge**, and the *body when electrified is* said to be **charged**.

When the *electricity is removed from the charged body it is* said *to be* **discharged**. Electricity may remain *upon* the surfaces of bodies as a *charge* or flow *through* their substance as a *current.*

Conductors are *bodies which readily allow electricity to flow throw them* or *circulate* freely on their surface, as, all the metals, the human body, and water.

Non-conductors *are those which offer very great resistance to the flow of electricity or its circulation on the surface*; they are also called **insulators** or **dielectrics**. Glass, sealing wax, gutta percha, and fatty substances are examples of these. The *difference* between a *conductor* and a *non-conductor is that of degree only* and not of kind.

Non-conductors are called **insulators** since they serve to *isolate* or insulate charged conductors from other bodies. To prevent electricity from being conducted away unto the earth or other bodies, charged conductors are supported by non-conductors. Non-conductors are also called **dielectrics**, because they *allow electrical influence to pass through them.* An electrified body acts inductively through non-conductors.

Electrical field is the *space round an electrified body within which it exerts force.*

All bodies derive their electricity from the earth, and also electricities of all bodies ultimately flow to the earth, for this reason the earth is called the **common reservoir**.

8. Proof plane and its use—It consists of a small gilt pith ball or a disc of tin foil, provided with a glass handle. When this is applied to the surface of an electrified body, it will, on removal, carry away some of its electricity, which may be tested by a charged electroscope at a distance. We may thus test the electrification of a body, too feebly electrified to show directly attraction and repulsion.

It may be noticed that by means of this apparatus we test the strength of the field, close to the point on the conductor at which it is applied, for when the proof-plane is brought in contact with the surface of the conductor, it forms a portion of the surface, and the same quantity is distributed over it. Thus the proof-plane carries away the charge, which will measure the strength of the field close to the conductor at the point where it is applied.

It is assumed here that the proof plane is so small that it can be charged from the conductor without sensibly altering its distribution or weakening its charge.

9. Laws of electrical attraction and repulsion.—(1) *Two bodies charged with the same electricity repel each other; two bodies charged with opposite electricities attract each other.*

2. *The repulsions or attractions between two electrified bodies are in the inverse ratio of the square of their distances (when the distance is very great compared with the dimensions of the bodies).*

3. *The distance remaining the same, the force of the attractions or repulsions of electrified bodies is directly as the product of the quantities of electricity with which they are charged i.e., if the charge of one of the electrified bodies be increased twice, the force will be increased in the same proportion.*

The first of these laws has been already established; the second and third may be demonstrated by Coulomb's Torsion Balance.

10. Distribution of electricity on the surface of bodies.—If electricity is produced at any part of a non-conducting body it remains there and does not flow over the surface or at most flows very slowly. Thus if a glass rod is rubbed at one end only that part remains electrified, but when a charge is given to any part of a conductor placed on an insulating support it instantaneously distributes itself *all over the surface*, though *not uniformly* over all points of it. The charge remains on the surface tending constantly to escape and even flies off when no resistance is offered by any body. That *the charge remains on the surface* only *is proved by* the *fact that* the *distribution is independent of the nature of the interior of the* conductor *i.e.*, if the shape remains the same, the charge will distribute itself in the *same manner* over the surface, no matter whether it is solid, hollow, or it consists of a non-conductor (such as wood) covered with a conducting leaf (as tinfoil).

11. Experiments. of surface distribution.—**I.** A hollow metal globe is placed on an insulating stand and is provided with metal hemispheres, having glass handles, which closely fit the globe. The globe is then electrified and the two hemispheres are placed round the globe touching each other. If the hemispheres are now suddenly separated they are found to be electrified and the globe indicates no sign of electrification. This shows that the whole of the electricity has passed to the external hemispheres. This experiment was performed by **Biot.**

II. If a hollow metal ball having a small aperture at the top be placed on an insulator and the interior charged with electricity, it will be seen that the whole of the electricity has flowed over the surface and there is not the least within. If paper strips be attached by their upper extremities both to the external and internal surfaces of any insulated globe or cylinder and the latter connected with the machine, the outer papers will be seen to be repelled by the surface, while the inner ones will show no sign of electrification. This proves that there is no electricity within a hollow charged conductor, the electricity remains on the outer surface only, and consequently the papers on that surface being charged with similar electricity are repelled.

12. Limitations.—The *foregoing law* that electricity resides only on the surface *is limited* only *to free* and *statical charges* (*i.e*, to electricity at rest). It does not hold good (1) when *electricity flows in a current*, for then it flows through the substance of the conductor, (2) when an *electrified body* is *placed inside* the hollow conductor, for then it will act *inductively* and attract the opposite kind of electricity to the *inner* side. Thus when electricity is *bound* it might remain on the inner surface.

When accumulated on the surface of bodies electricity tends to pass off to adjacent bodies with a certain effort which is known as its **tension**.

Tension then *denotes only the mechanical stress on a dielectric due to accumulated charges.* It increases with the quantity of electricity and when the resistance is overcome it springs off to the adjacent body in the form of a bright spark.

13. The Power of Points—*The manner in which electricity is distributed* on the surface of a body *varies with its shape.* If it be spherical the charge is uniform. In all other cases the *charge and* consequently the *tension increases with the curvature.* Experiment shows that there is more electricity on the edges and corners of bodies than upon their flatter parts.

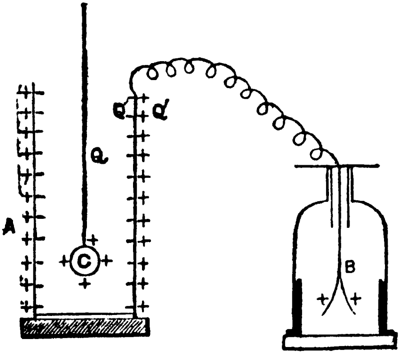
Electrical density at *a point is the number of units of electricity on a unit area containing the point*, on the assumption that the distribution is uniform over this small surface. It has been said that the density increases with the curvature of the conductor, which means that electricity always tends to accumulate towards the most curved or elongated parts, or towards the points. This accumulation produces a greater tension; and at the **points** *where the curvature is infinite its tension is infinite also,* and so it *escapes slowly into the air.* *This* *property of points of allowing elelricity to escape slowly is called the* **power of points.**

14. Electrical Induction.—It is the influence which an insulated electrified body exerts on an unelectrified body in the neighbourhood, decomposing the neutral fluid, attracting the opposite kind and repelling the like kind of electricity. *To prove this*, suppose an insulated metal cylinder, provided with several pairs of pithball-pendulums at equal distances from one end to the other,to be brought near the conductor of an electric machine. The pendulums are found to diverge, the greatest divergence being near the ends. Near the middle the pith-balls do not diverge at all, showing that there is no electricity present there. By bringing electrified glass or resin rods near the cylinder it may be proved from the greater or less divergence of the pendulums that *the electricity* accumulated *at the end nearer to the prime conductor is opposite to that in the conductor.* But if the *cylinder is connected with the ground* by a metal conductor, while it is under the influence of the machine, the machine by induction will separate the two electricities of the cylinder, attract the opposite and repel the like kind to the farthest end of the conductor. In this case the farthest end is not the other end of the cylinder, (since the cylinder and the earth together are now considered as one conductor,) but the other end of the earth, and therefore the *free electricity will pass to the earth* and *the pendulums* in the other end of the cylinder *will remain collapsed. If now the connection* with the ground *is cut off* and the *cylinder removed* away from the prime conductor the *pendulums on* all parts *will be repelled* and the body will be found to be electrified all over the surface.

Thus a body may be *charged by induction*, but it has been said that a body may be *charged also by conduction* by simply connecting it with the machine by a metal. There is a great *distinction between the two.* In *electrifying a body by conduction* it is *insulated* from the *ground* and *connected* with the *machine*, whereas in *electrifying by induction* the body is *connected* with the *ground* and placed *near* the machine but not connected with it. In the former the charging-body (*i.e.* the machine) *imparts like* electricity to the body electrified and therefore *loses* a portion of its own, but in the latter process, the *quantity* in the charging body remains *unaltered* and the unelectrified body loses a portion of its neutral fluid and becomes charged with opposite electricity. Good conductors are most easily electrified than bad conductors, but the electric state of the latter, when once charged, is more permanent. This property is analogous to 'coercive force' in magnetic bodies.

15. Ice-pail Experiment—The total *amount of* opposite *electricity* **induced** *on surrounding* conductors by any electrified body **is equal to** *the body's own charge. i.e.*, the **inducing electricity**. This was proved by Faraday in his Ice-pail experiment. An electrified ball was introduced into a hollow cylindrical body the outer surface of which is connected by a metallic chain with a gold leaf electroscope. When the ball is lowered, the divergence increases at first, till it attains a certain point ; after this there is no change in the divergence, even after the ball is brought in contact with the inner surface of the cylinder. This proves the law.

Let Q be the quantity of +ve electricity in the ball, Q′ the quantity of opposite —ve electricity in the inner surface of the cylinder. The divergence is caused by Q′ quantity of +ve electricity.



If Q be not equal to Q′, it is either *greater* or *less*.

If Q be greater than Q′, a certain quantity of +ve electricity will remain in excess after the contact, the *divergence* will be greater.

If Q be less than Q′, a certain quantity of—ve electricity will remain in excess ; the *divergence will be less.*

But since it has been observed that the divergence remains *unchanged* , ∴ Q = Q′

16. When *an electrified body* is *brought near* (1) a *metallic ball suspended by a silk thread*, the *ball is attracted*, since negative electricity is induced on the nearest side of the ball, and positive electricity on the farthest side, and therefore attraction prevails over repulsion ; (2) *near a ball connected with the earth* by a conducting wire, the *attractian will be greater* than in the first case, for it is entirely charged with negative electricity and there is no repulsive force due to the positive electricity to be overcome.

Electric paradox.—A positively electrified particle repels every other positively electrified particle *but two conduetors charged with similar electricity do not necessarily repel each other. If one of them be larger* repulsion will be observed at distances exceeding a certain limit and attraction at nearer distances. The reason is that besides its own charge the neutral fluid of the smaller one is separated by *induction*, the *farther* face is charged with the whole of the positive electricity while the nearer face becomes charged with negative electricity. The repulsion is at first greater ; because the quantity of positive electricity is greater (therefore repulsion overcomes the attraction of the opposite electricity) ; but as the distance diminishes, the attractive force (due to the induced distribution) *increases more rapidly* and finally exceeds repulsion.

QUESTIONS.

1. What is electricity ? (1). What are its chief sources ? (2). Prove experimentally that there are two kinds of electricity (3,4). Prove that in very electrical separation the quantities of the two electricities separated are *equal* (5). Is the nature of electricity developed in bodies always the same ? On what does it depend ? (5).

2. What are the Hypotheses brought forward to explain the electrical phenomena ? (6). What are the objections ? What are dielectrics ?

3. Enumerate the laws of electrical force (8).

4. Describe the experiments to prove that there is no electricity within a hollow conductor (12). Mention any limitations to this law (13). What do you understand by the "power of points" and how can you explain the phenomenon ? (14).

5. What is "electric induction" ? Describe the two methods of charging bodies and find out the distinctions (15). How did Faraday prove that *the inducing charge is equal to the induced charge* ? (16). When a positively electrified conductor is placed near another positively charged conductor at first repulsion takes place and then attraction. Explain this (17).

ELECTRICAL MACHINES.

1. The electrical machine was first invented by Otto von Guerick in which a ball of sulphur was made to rotate about an axis and the hand of the worker was used as a rubber. It has been gradually improved since, the sulphur has been replaced by glass cylinders or circular plates, and instead of the hand serving as a rubber cushions are used.

2. Plate electrical machine.—This is a modified form of Ramsden's machine. It consists of a circular piece plate-glass always coated with shellac or paraffin, (glass being a hygroscopic substance) and mounted on a horizontal axis capable of being turned by a handle. The plate revolves between two sets of cushions of silk, or of leather stuffed with horsehair and the surface covered with powdered amalgam of zinc and antimony. These two sets of cushions press the plate at points directly opposed to one another. The machine is provided with silk flaps. In front of the plate are two metallic rods provided with a series of points on the sides opposite the glass. These rods are fixed to two large metal cylinders placed on insulated supports and connected together by another metallic rod, which are called the *prime conductors.*

a. The action of the machine—Electricity is generated by the friction of the rubber against the plate, the glass becomes positively, and the rubber negatively electrified. But when the machine is worked the rubber is generally connected with the ground, so that the negative electricity passes off to the ground as fast as it is generated. Tne positive *electricity on the glass acts inductively* on the *conductor* attracting and combining itself with the negative electricity through the points, the conductors therefore remain charged with positive electricity.

3. Precautions in using the machine.—The damp and dust must be avoided, the surface of the glass plate and the rubbers should be warmed at the time of making experiments. All *points* should be avoided except where they are desired, because electricity is likely to be discharged through them. Therefore the rods used in the construction of the machine are made with knobs.

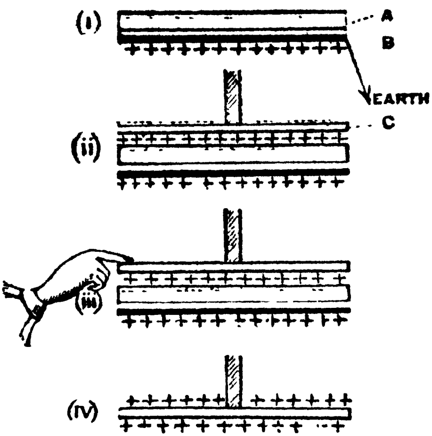
When the machine works, whatever precautions be taken *there is always a limit to the quantity of electricity accumulated on the conductor*, for as electricity is being accumulated, its *tension increases* and when it exceeds *the resistance offered by the air* and the *supports of the conductors*, electricity escapes. From this moment the loss is equal to the electricity generated, and consequently the quantity on the conductor remains constant.

Two flaps of silk extend over the two quadrants or the portions of the disc from the rubbers nearly to the combs. They *are used* to protect the electrified portions of the disc from dusts and *to prevent the electricity being dissipated away.*

4. Measurement of the charge.—The amount of charge in the conductor is measured by *Henley's Quadrant electrometer* generally placed over the prime conductor. *This* electrometer *consists of a wooden rod to which is attached a semicircular card-board scale.* In the centre of the circle is a small index terminating in a pithball and movable on the axis through the centre. Being attached to the conductor the pithball is charged with the same kind of electricity and is repelled by the conductor. This pithball ceases to rise when the limit is attained, the charge is measured by the angle through which the pithball is repelled. If a *point* be held near the prime conductor of the machine electrometer falls, for the positive electricity in the machine induces negative electricity on the point which combines with it and brings the machine to the neutral state.

5. Electrophorus.—This instrument was invented by Volta for the purpose of *procuring by induction an unlimited number of charges* of electricity *from one single charge.* It consists of *a cake of resin placed on* a metallic disc or wooden *mould covered inside with tinfoil,* called the *form* or *sole.* There is another *round disc of slightly smaller diameter, made of metal* or of wood lined on the under surface with tin foil, and *provided with a glass handle.* This is called the *cover.*

6. *The working of the apparatus.*—All the parts having been well warmed, the cake is rubbed or briskly flapped with a catskin by which it becomes charged with negative electricity. The cover held by the insulating handle is then placed on the cake and its upper surface touched with the finger, the negative electricity of the cake acts inductively on the cover, attracting positive electricity to the lower surface of it, the negative electricity (on the cover) being repelled passes through the finger into the earth. The induced positive charge, being bound by the negative charge on the cake, will remain on the lower surface of the cover. If now the cover be lifted by its handle the positive charge on it will no longer remain *bound,* but distribute itself *on both sides* of the cover, and may be used to give a spark. The electricity thus yielded by the instrument is not obtained at the expense of any part of the original charge, so that by



A = resin cake ; B = form ; C = cover

repeating the process sparks may be obtained from the cover infinite number of times.

When the cover is placed on the cake, there is only contact at very few points and every where else a thin layer of air between the cake and the cover. *The action* between the cake and the cover *will* therefore *be almost wholly induction.*

The *form or sole* is used to lower the tension of electricity in the cake and thus to prevent the electricity being dissipated away into the air. The negative electricity on the surface of the cake acts through it inductively on the form. The opposite electricity thus developed by induction binds down a portion of the electricity in the cake and thus lowers its tension. But on putting the cover down on the cake the induction will be almost wholly between the cake and the cover, owing to the much greater nearness of the cover. On lifting up the cover the induction between the cake and the form is again restored and thus the charge on the cake is preserved.

7. Bound and free charge.—The charge of electricity on a conductor is said to be **bound** *when it is attracted by the presence of a charge of opposite kind.* The term **free** is *applied to the ordinary state of electricity* upon a charged conductor *not attracted* by a charge of opposite kind. The *latter* *flows away* instantaneously to the earth *when the charged body is connected* at *any* point *with the earth* by a conductor, whereas *the former* will *remain on the surface,* no matter whether the body is connected with the earth at that point or not.

8. **Gold-leaf electroscope.**—It consists of a wide mouthed glass jar into the neck of which a cork is fitted. A brass rod passes through the cork. The top of the rod terminates in a knob or a disc, and to the bottom two strips of gold leaf are attached. The glass being hygroscopic is covered with shellac varnish. The air within is also made dry by quicklime. The instrument may be charged either by conduction or by induction. I. *By conduction.*—In this method the charged body is placed in *contact* with the knob. Electricity passes into the rod and the leaves diverge. The *kind of electricity* is determined in the following manner. When it remains electrified any body charged with the same kind of electricity, and brought near the knob, will repel the electricity of the latter towards the leaves and thus the leaves will diverge more. But if a body charged with opposite electricity be brought near the knob the whole of the electricity in the rod will tend to be accumulated in the knob and consequently the leaves will collapse. Therefore knowing the kind of electricity present in the rod brought near the knob (*i. e.,* bringing an ordinarily electrified glass or resin rod near the knob), and observing whether the leaves diverge or collapse, the kind of electricity in the electroscope can be determined.

II. *By Induction,*—In this, the electrified body is brought *near* the knob, which acts inductively upon the instrument attracting the opposite kind towards the knob and repelling the same kind towards the leaves. The *leaves* will *diverge* now *with* the *same* kind of electricity as that in the charged body. Then *the knob is touched with the finger,* the free electricity at the leaf-end flies to the earth and *the leaves collapse.* If now the *finger* is *taken away first* and *then the charged rod,* the bound electricity will become free and distribute itself over all parts, and the *leaves* will *diverge again,* (but in this case *with opposite electricity*). The *kind of electricity present may be detected as in the first case.*

Two strips of tin foil are attached to the inner surface of the glass case, *opposite to the gold leaves.* These two strips are connected with the tin foil covering the base of the instrument.

When *the strips are used*, the instrument becomes more delicate, for then the *divergence of the leaves will be greater*. The reason is that the electricity in the leaves will act inductively upon the strips and the opposite induced electricities in the two strips will attract the two leaves and cause greater divergence.

Caution.—To charge the instrument by induction care must be taken to remove the finger first and then the charged body, for otherwise (*i. e.*, if the electrified body be removed *first*) the bound electricity in the instrument will become free and pass through the body into the earth and there will be no electrification.

9. Experiments.—When a finger or a metallic rod held by the hand is brought near the conductor of an electrical machine, a spark of light is produced, for electricity in the conductor acting *inductively* on the finger or the rod attracts the opposite and repels the similar electricity, the latter passing into the earth through the body. The electricity on the conductor will tend to combine with the electricity on the finger or the rod, and when the tension becomes greater than the resistance of the air between, the two electricities combine and the spark is produced. Thus a body may be *discharged* by conduction by connecting it with the earth by a wire, so that electricity will pass to the earth ; or by holding a pointed rod near it by the hand, so that electricity will be neutralised by the induced electricity combining with it through the point.

10. Head of hair.—If a head of hair is suspended by a metallic chain from the conductor of the machine, each hair will become charged with the same electricity and will be repelled by the other.

11. Electric chime.—It consists of a horizontal metal bar from the ends of which two bells are suspended by metal wires ; from the middle point of the bar another bell is suspended by a silk thread but this is connected with the earth by a metal chain. Between these bells are two brass balls suspended from the bar by silk threads. When the horizontal bar is connected with the machine, the bells on the ends are charged, they act inductively on the balls and attract them. When they touch these bells the opposite electricity in them combines with a portion of electricity in the bells. Now there remains in them the same kind of electricity, consequently they are repelled by the bells on the ends, when they touch the bell in the middle and their electricities pass to the earth. This process of alternate attraction and repulsion is repeated and the bell is rung.

12. The **dancing of pith-ball dolls** placed between two horizonal metal discs, one metallically connected with the earth and the other with the machine can be explained as above.

13. **Electrical whirl.**—*The effects of points* in discharging electricity from the surface of a conductor may be proved by many experiments. On fastening a pointed needle to the conductor it discharges so effectively that a brush of pale, blue light will appear at the point. If a candle be held near the point the flame will be blown away by currents of electrified air repelled from the point. This is also proved by *electric vane.* It consists of four wires terminating in points and all bent in the same direction and fixed in a metal cap which rotates on a pivot. When this is placed on a machine *it begins to rotate in a direction opposite to that of the bends* of the wires. This is due to repulsion between electricity on each of the points and that which it imparts to the particles of the surrounding air by conduction owing to the property called the power of points. The two opposite points are acted on by equal and opposite parallel forces and the result is the rotation. The action here is not due to induction.

14. **Luminous pane.**—It consists of a glass plate on which is fastened a narrow strip of tin-foil folded parallel to itself for a great number of times. Breaks are made in these strips by cutting out bits from several parts. If one end of the tin foil is connected with the machine and the other with the earth by a metal chain electricity passes through these strips and sparks will be seen at each break. Similarly tin foil strips may be arranged within a glass globe or a tube and sparks may be observed. The portion of the strip connected with the machine is charged with electricity, it acts inductively on the next bit, attracting the opposite kind and repelling the like kind. This free electricity acts inductively on the next, and so on to the other end, where electricity passes to the earth. Sparks are caused by these opposite electricities (of the two consecutive bits) combining together across the breaks.

15 **Volta's cannon.**—It demonstrates that electricity can effect chemical combination. It consists of a brass cannon placed on an insulating stand into the touch-hole of which a glass tube is inserted. A metal wire terminated in knobs on

both ends is placed within the glass tube so that one knob is outside the cannon and the other inside it, but not touching the inner surface. The cannon is filled two-thirds with hydrogen and one-third with oxygen and is closed by a well-fitting cork. If the cannon is connected with the ground by a metal chain and a charged body brought near the outer knob, this body will act inductively on the wire attracting the opposite electricity and combining with it with a spark while the same electricity will be repelled to the inner knob where it will act inductively again. Similar electricity will be repelled and will pass through the chain into the earth while opposite electricity will be attracted and will combine with it. A spark will be produced within the cannon, the two gases will combine with a loud explosion and the cork will be driven out with a very great force.

16. **Electric egg**—It is an instrument to prove the resistance of the air. It is a hollow oval glass vessel provided with a metal cap at each end. Through one of these caps a metal rod passes, and through the other a metal tube provided with a stop-cock. The vessel is exhausted of air, then connected with the machine and the tube connected metallically with the ground. The globe becomes filled with a feeble violet light. If the air be then allowed to enter, the resistance is increased, continuity breaks and light is seen only as an ordinary spark.

17. **Condensers and Leyden jars.**—An arrangement for holding a large quantity of electricity is called a *condenser*. That which is often used is known as Epinus' condenser. It *consists of two metal plates placed on insulated supports* one connected by a wire with the machine and the other by a chain with the earth. Between *these plates is a plate of glass somewhat larger*. The positive charge upon the plate connected with the machine will act inductively across the glass on the other, and will repel the positive electricity to the earth, binding the negative electricity to the nearest face of the plate. The negative charge will attract and bind down a portion of the positive charge of the first plate to the face fronting the glass and thus decrease its tension. There will be a change in the distribution of electricity in the first plate and it will be able to receive a fresh charge. This fresh charge will act inductively on the second plate and there will be a fresh accumulation of negative charge on that plate. This will alter the distribution of the positive electricity in the first plate which will receive a fresh charge

for the second time and so on, the process will continue, and electricity will be condensed or accumulated. But each time electricity passes from the machine to the first plate a portion of it only is bound down by the other plate. The tension of free electricity on the first plate is continually increased, till it is equal to that of the machine, when it will no longer receive any more charge. This is the limit the charge of the condenser.

18. **The capacity of a condenser.**—The quantity of electricity which can be accumulated on each plate *varies directly* as *the tension of the machine* and *the capacity* of the condenser. *The capacity i.e.*, the quantity of electicity necessary to raise it to a fixed or unit tension varies directly *the surface of the metal plates*, and *inversely as the thickness of the dielectric interposed.* It varies also with *the nature of the* dielectric *(i. e.*, inductive capacity of the dielectric*)*, for in this instrument if instead of glass another body such as shellac be placed the capacity will be different.

19. **Discharge of a condenser.**—A condenser may be discharged *slowly or instantaneously.* To discharge it *slowly* the *plate* containing the *free* (positive) electricity is *first* touched with the finger, free electricity escapes into the ground and a *portion* of the *bound* (negative) electricity in the other plate becomes *free.* If then this second plate be touched with the finger, free (negative) electricity in this will flow into the earth and a portion of the *bound* (positive) electricity on the first becomes free. Thus the *instrument* will be slowly discharged, if the two plates are alternately touched beginning with the free (positive).

20. **Discovery of Leyden Jar.**—The attempt of Cuneus and his master to collect the "supposed electric fluid" in a bottle partly filled with water led to the discovery of Leyden Jars. The bottle was held in the hand and a wire was placed connecting a machine with the water. On touching the wire he received a shock. Here the water in the vessel, served as the collecting plate, the hand as the condensing plate, and the vessel itself as the dielectric.

21. **Leyden Jar**—It consists of a glass bottle the inside of which is either coated with tinfoil up to a certain height or filled with thin leaves of any metal. The outside is also coated with tinfoil up to a certain height. A brass knob is fixed on the end of a stout brass wire which passes downward through a cork fitting into the neck of the bottle. The lower end of the wire is

loosely connected by a brass chain with the inner coating. The jar is charged by connecting one coating with the machine and the other with the ground either by holding that with the hand or by metal chain. The positive charge is imparted to the coating connected with the machine; it acts inductively on the other coating, attracting the negative electricity to the nearest face and repelling the positive to the earth. Electricity is accumulated in this as in any other condenser, so the explanation is the same, and like the condenser, it may be discharged either slowly or instantaneously. To discharge it slowly, the jar is placed on an insulating stool, and the two coatings are alternately touched with the finger, the coating containing the free electricity must be first touched. It is discharged instantaneously by a discharger by touching first the coating containing bound electricity and bringing the other end near the other coating. The *capacity* of a Leyden Jar depends upon conditions stated for the condenser.

22. Residual charge.—When a jar has been discharged and allowed to stand for some time, it exhibits a charge, called the *residue charge*, so that the jar may be again discharged and a second *residue* may be left, feebler than the first and so on 3 or 4 times. It can be proved mathematically that the instrument may be discharged indefinitely but after 4 times the discharge becomes so feeble that it cannot be detected by the electroscope. This is due to the fact that not only do the electricities on the two coatings adhere to the surfaces of the insulating medium which separates them,but they *penetrate* to a certain extent into *the interior* so that when first discharged only the electricities on the surface combine. After a time the electricities that penetrated the dielectric no longer held by the same force, come to the surface. They combine with a spark when the instrument is discharge for the second time and so on. As a proof of this,if a condenser is taken with moveable metal plates,charged,left in that state for some time and then *discharged*,the metal coatings and the two faces of the insulator will show no sign of electricity. But after sometime each face will exhibit the presence of some electricity. The *residue* charge depends on the *amount* of the charge and on the *time* during which it remained charged.

23. Electric battery.—It consists of a number of jars whose inner coatings are connected with each other bymetal rods and the outer coatings are connected with each other by tin foils and also with the ground by a metal chain. The power of the battery *depends upon the number of jars.* In order to discharge the battery care must be taken to touch the outer coating first.

24. Condensing electroscope.—Volta applied the principle of condenser to gold-leaf electroscopes by which a greater degree of delicacy was attained. It is an ordinary gold-leaf electroscope in which the rod to which the gold leaves are affixed terminates in a disc intead of a knob and there is another disc of the same size, provided with an insulating glass handle. The discs are covered with shellac varnish. To detect electricity, one of the plates is touched with the electrified body and this plate becomes charged and acts inductively on the other plate which is connected with the ground (either by a metal chain or by touching it with the finger). By induction the opposite electricity is attracted to the nearest face of the plate and like electricity passes into the ground. The electricities become thus accumulated, but the leaves do not diverge because electricities remain bound by each other. If the finger is removed and *then* the source of electricity, the two leaves will remain in the same state but on raising the plate the bound charge will become free, and distribute itself on the two leaves which will then diverge.

25. Effects of electricity.—*Electric discharge is the recombination of the two electricities. It may be either continuous or sudden. The former* '*takes place* when the two oppositely charged *bodies are metallically connected*, so that there is a continuous flow of electric current *In* the case of *sudden discharge the opposite electricities accumulate on* the surfaces of the *two* adjacent *bodies*, till their tensions become greater than the intervening resistance, when *they suddenly combine* together. From the manner in which bodies are affected by the electric discharges, effects have been divided into physiological, luminous, heating, mechanical, magnetic, and chemical ones.

I. Physiological effects—They are those that are produced on living beings or those recently dead. They generally consist of muscular contraction or excitement on the sensibility of muscular tissues through which electricity passes. A shock is given to a body through which the current passes. This shock may be given to a larger number of persons simultaneously by means of a Leyden jar. In order to do this, these men must form a chain by joining hands. The man at one extremity will hold the jar and the one at the other extremity will touch the knob.

II. Luminous effects of electricity have been seen in the case of electric egg and magic pane. In the ordinary Leyden jar if the outer coating be of shellac strewed with metallic bits ; on connecting the outer coating with the ground, and the inner coating with the machine, spark will be seen to pass over the interval between the bits as electricity passes.

III. **Heating effects.**—When an electric spark is made to pass through any inflammable substance the body is ignited. For this purpose is used a small glass cup through the bottom of which passes a metal rod terminating in a knob within the cup. This is used as a stand. A quantity of the inflammable liquid sufficient to cover the knob is poured into the cup. The knob of a Leyden Jar is brought near the knob in the cup, the outer coating being connected by a metal chain with the other end of the rod passing through the cup. A spark will pass through the liquid and ignite it. When a battery is discharged through a metal wire it becomes heated and sometimes melted.

IV. **The mechanical effects** are the violent expansion and sudden fracture caused by the discharged electricities through a bad conducting substance. *To demonstrate this* a plate of glass or any other nonconductor is placed between two needles or pointed metal rods. If one of them is connected with the outer coating of the Leyden Jar and its knob is brought near the other rod, electric spark will pass through the plate which will thus be perforated.

V. In order to prove the **chemical effects** (*i.e.*, the decomposition and recombination) that take place when electric spark passes through bodies, a mixture of two gases in the proportion in which they combine (as for instance H_2 and O) is taken, a spark is made to pass through it and combination takes place. Water is also decomposed into the constituent gases by electricity.

VI. **Magnetic effects.**—A steel wire is magnetised by placing it at right angles to the wire through which a Leyden Jar is discharged, or by placing it within a tube round which insulated copper wires are coiled, and discharging the Leyden Jar through the copper wire or connecting one end of the wire with the machine and the other with the earth.

(*a*) **Electric portrait.**—The *fusion of metals by electric discharge is made use of in making electric portrait.* To do this a thin card is taken and a design is cut out in the middle. The two borders are covered with two pieces of tin poil, a piece of gold leaf is placed over the design, the middle part is covered with paper and pressed hard by a pressing machine. The whole thing is placed upon a piece of silk. Electricity is discharged through the tin foil and gold leaf is volatilised and forms a brown coating on the silk reproducing the design on the silk.

(*b*) The *leaves* of a gold-leaf electroscope connected with the ground and placed near the machine, will *diverge, whenever the spark is taken from the machine,* for at this time a portion of the induced electricity becomes suddenly free and distributes itself over the rod and the leaves.

QUESTIONS.

1. Describe the plate machine and its working (2, 3). How can its charge be measured ? (4). Prove that there is a limit to the charge (4).

2. Describe the working of the 'electrophorus' (6). Define 'bound' and 'free' electricity (7). Describe "Proof plane" and state its uses.

3. Describe the gold-leaf electroscope (8); an electrified body is, brought near it, the leaves diverge, it is then touched by the finger the leaves collapse ; now the finger is taken away and then the electrified rod, leaves diverge again :—Explain this (8).

4. When the tip of a finger is brought near a machine, sparks are seen :—Explain this (9).

5. Explain the working of :—electric chime (11) ; luminous pane (14) ; electric egg (16) ; electric vane (13) ; On what principle is Volta's cannon constructed ? What does it prove ? (15).

6. What is a condenser and how is it charged ? (17). How is it discharged ? (19). Enumerate the conditions on which its capacity depends (18).

7. Describe the construction of a Leyden jar (21). How is it discharged ? (21). Is it a condenser ? What is understood by the "residual charge" and how can its existence be proved ? (22). Describe Volta's condensing electroscope (24).

8. Describe some experiments to illustrate the different effects of electric discharge. (25). Describe the method of making electric portraits (25 *a*). What are the different modes of electric discharge ?

9. The leaves of a gold-leaf electroscope, connected with the ground by a wire and placed near an electrical machine, diverge whenever a spark is drawn from the machine :—Explain this. (25, b).

CURRENT ELECTRICITY.

1. Besides friction there is another powerful source from which electricity is produced by chemical action. It has been already said that electricity flows away from a charged body through any conducting substance such as wire. If by some means electricity could be supplied to the body as fast as it flowed away, continuous *current* would be produced.

2. **Galvani's Experiment.**—The discovery of dynamical electricity or electric currents originated with Galvani. A recently killed frog was suspended from an iron railing by means of a copper hook passing between the vertebral columns and the nerves on each side of it. When the leg of the animal came in contact with the iron railing it was seen to be violently contracted. He had observed similar contraction when electricity from a machine was made to pass through the leg. This led him to imagine that *there is an electricity inherent in the animal*, it was generated by the frog's leg itself and when the nerves and muscles were

metallically connected, the electricities passed from the nerves to the muscles. Galvani's attention was thus drawn to the animal tissues and so he called this *animal electricity.* He performed many experiments, in one of which he observed that the *contraction* was *greater* when *different metals* were *used* than when there was only one.

(*a*) **Volta's Explanation**—This singular fact led *Volta* to think that the disengagement of electricity is due to the *contact of two different metals.* His attention was naturally directed to *the metallic portion and* he *thought that animal portion served as a conductor.* To prove his theory, commonly known as *the* **contact theory,** he constructed two instruments ; one, *Volta's condensing electroscope*, and the *other Voltaic pile.*

The description of the electroscope is given in the chapter on frictional electricity (art 24). To shew the production of electricity in this, the zinc end of a bar made of two dissimilar metals (zinc and copper) soldered together is held in the hand and the copper end is touched against the lower copper plate, the upper plate being at the same time joined to the earth or touched with the hand. Electric separation takes place at the point of contact of the dissimilar metals, and when the upper one is lifted the leaves diverge. If the rod be made of copper only no electric separation takes place. If the copper end is held by the hand and the disc is touched by the zinc end no electrical separation is observed, since there is electrical separation in one direction at the surface of junction, also in the opposite direction at the point of contact of the rod with the disc, the one is neutralised by the other. The second apparatus proves it more convincingly.

Volta's pile—It consists of a number of discs, each being composed of a copper and a zinc disc soldered together. These discs are placed one above another having their zinc faces in the same direction, but each of them is separated from the other by a piece of cloth or blotting paper moistened with brine or acidulated water. When the copper face of the first disc, and the zinc face of the last are connected by metal wire electricity will pass through it. Here electricity is generated in each disc, composed of two metals connected together, one kind is accumulated on one end the other is collected at the other end. So the quantity of electricity separated will increase in proportion to the number of these discs. From these experiments he established the proposition that when *two heterogeneous bodies* are in contact one of them *always assumes the positive and the other the negative electrical condition.*

3. Chemical action in electric disengagement.—Fabroni observed that in the Volta's pile after the experiment, zinc discs become oxidised in contact with the acidulated water. This led him to think that *chemical action is the cause of electric separation.* He found many followers in England. De La Rive repeated Volta's experiments with the condensing electroscopes, and showed that if zinc be held in a wooden clamp all signs of electricity disappear and that same is the case if zinc be placed in gases which exert no chemical action upon it. Thus he concluded that in Volta's original experiment the disengagement of electricity was due to the chemical action resulting from perspiration and the oxygen present in the atmosphere. It is found that all chemical actions are accompanied by electrical separation, and that these chemical actions go on as long as the current passes. Electric separation is also accompanied by chemical action, but it is not known whether the first is the effect of the second or the second that of the first or both the effect of another cause common to them. However the origin of electricity is still a moot point.

4. Remarks.—The objection to Volta's experiment lies in the fact that there are in most cases other contacts besides the one investigated, which may produce the observed effects, for in all these experiments *it is very difficult to prove that the clean metal surfaces themselves come into contact*, first, because *oxygen and moisture in the air may act chemically* on the surfaces ; secondly, owing to the remarkable property possessed by metals of condensing gases on their surfaces, these *condensed gases adhere to the surface with greater pressure* than that of an atmosphere. So these objections cannot be entirely overcome even when experiments are conducted in gases which do not act on the metals, in air completely dried or even in a vacuum.

Explanation of electrical separation by contact.—It is clear from the kinetic theory of molecules that when molecules of two different bodies (or of the same body at different temperatures) impinge on each other as at the surface of contact, they cannot accommodate themselves to each other's motion, but constrain each other ; this constraint produces a loss of energy. It is this loss of energy owing to the unsymmetrical oscillation of the molecules at the surface of contact which reappears as the energy of electrical vibration of the molecules at the surface of contact *i.e.*, as the energy of electrical separation. But the principle of the conservation of energy (*i.e.*, the principle that the total amount of energy remains constant in the universe) precludes a mere contact force from furnishing *a constant supply of current*, hence the latter *is ascribed to the chemical action*. Also the fact that the electric current is proportional to the chemical action (in the cell) goes against the *contact theory of Volta*.

Again an experiment performed by Sir Wm. Thomson goes in favour of the contact theory. A very light metal bar was suspended by a fine wire over a metal ring made up of two halves, one of copper and the other of zinc. When the two halves were in contact the bar deflected one way or the other according as it was positively or negatively electrified. But when a ring of uniform metal was placed under the needle or the two halves were connected by a drop of water, the needle was not at all deflected. These things go to show that both contact of dissimilar bodies and chemical action are necessary to produce the effect ; that the laws regulating the electrical separation and the current are intimately connected with the nature of the substance and the amount of chemical action.

5. Voltaic cell and the chemical action in it.—The cell consists of a plate of zinc and a plate of some less easily oxidisable metal (for instance copper, platinum or gas carbon) partially dipped in some dilute acid (generally sulphuric). Hydrogen is *slightly* disengaged from the zinc plate when it is amalgamated. The chemical reaction may be represented by the following equation.—$Zn + H_2\ SO_4 = Zn\ SO_4 + H_2$ (Zinc and sulphuric acid give zinc sulphate and hydrogen gas). No action takes place on the surface of the copper or carbon plate. Also *by* means of *a* very *delicate electroscope zinc* plate *may be seen* to be slightly *charged with negative* and the *copper* plate *with positive electricity.*

But when *the circuit is completed either* by placing the plates *in direct contact* or by *means of a metal wire*, the *chemical action* of the acid the zinc plate *is increased* and hydrogen is evolved, but it will be noticed that the *gas* is seen to evolve at the *surface of the copper plate* (or any other less oxidisable substance used). If the connecting *wire* be examined, it will be found to *possess the remarkable properties characteristic of the discharge of opposite etectricities present in the two plates.* So long as these plates remain in the liquid, the electric conditions of these are restored as soon as they are discharged ; there is then a continuous discharge of electricities through the wire and when this takes place the wire is said to be traversed by an electric *current.*

6. Definitions—A *series of electrical discharges in rapid succession through a conducting wire connecting the* two *plates of a cell is called an electric* **Current.**

The production of a current of electricity is always accompanied by chemical actions in the cell. This continues to flow along the wire as long as the chemical action goes on in the cell.

The quantity of electricity which flows through the sectional area of the circuit in unit of time is called the **strength** *of the* **current.**

This is proportional to the amount of zinc dissolved in an acid, and when the whole of the acid is neutralised by the zinc, the current ceases.

The **direction of the current** is the *direction in which positive electricity travels.*

This is a mere convention. *Within the liquid, the current flows from the generating to the collecting plate, outside i.e.,* in the wire *it flows in the opposite direction i.e.,* from the inactive to the active plate.

The plate which is more acted on by the liquid in the cell (zinc plate in the ordinary cells) is called the **generating** or **positive plate.** *The inactive plate* is called the **negative** or **collecting plate.**

The parts of the plate above the liquid where the two electricities are accumulated when the plates are not joined by a metallic wire are called the **poles or electrodes.**

The point where the positive electricity is accumulated when the plates are not joined *is called the* **positive electrode** and the point where the negative electricity is when the plates are not connected is called the **negative electrode.**

It must be borne in mind that the **negative plate has** the **positive electrode** and the **positive plate,** the **negative electrode,** *i.e.,* positive electricity is accumulated at the upper end of the negative plate, and negative electricity, at the end of the positive plate.

Electromotive force is *the force with which the electrical discharges take place through the connecting wire i.e.,* the force with which the current is driven along the wire.

A **voltaic battery** is an arrangement in which a number of voltaic cells are joined together.

There are two modes of joining cells to form batteries. (1) In the one all the positive plates are joined together ; all the negative plates are also connected and then they are joined by a wire. (2) In the second the positive plate of the first is joined to the negative plate of the second, the positive plate of the 2nd to the negative plate of the 3rd and so on ; the positive plate of the last is joined by a wire to the negative plate of the 1st.

The following is a brief summary of the different conditions of a voltaic cell :—

Thermal condition of the cell—*When* the two *plates* are not in contact there is no perceptible change of temperature, but when they are *in contact*, the *temperature* both of the liquid and the solid conductors is seen to *rise*. The *change* of *temperature is greater when* the *plates* are in *direct contact than when* they are *connected by a thin wire.* It can be shown that the total heat evolved is for all practical purposes equal to that which would be evolved on dissolving the same weight of zinc in the dilute acid. This shows that the action in the cell is a purely chemical one.

Chemical condition of the cell—While the plates are in contact, hydrogen bubbles are seen to stream up from the copper or inactive plate. After sometime it is found that the weight of zinc has been diminished and that zinc sulphate has been formed which dissolved in the liquid.

On separating the plates the stream of hydrogen bubbles ceases and if they are kept in the liquid for the same length of time *without contact* there is no evolution of hydrogen (when the zinc plate is amalgamated), no formation of zinc sulphate and no loss of weight in the zinc.

This shows that when zinc and copper plates are dipped in acidulated water, they assume different electrical conditions without any sensible action taking place ; but when they are placed in contact with each other, chemical action takes place and the tension between the poles is diminished. The action goes on so long as contact continues. By this chemical action zinc is converted into zinc sulphate and hydrogen is evolved.

Electrical conditions of the cell—When the *plates are not connected,* copper is charged with opposite electricity and zinc with negative electricity. When they are *joined by a short and thick wire*, the two electricities combine immediately and every trace of electrification disappears. On separating them again the two electricities instantaneously reappear. When the plates are *joined by a long thin wire*, the *two electricities* do not disappear immediately, because they now *combine slowly through the wire* which offers resistance to the passage of electricity. The tension between the poles as well as the quantity of electricity in each is diminished and can be made less and less by shortening or thickening the wire. This shows that there is in this case not a single discharge (as in a

Leyden Jar, but a continuous discharge depending on the connecting wire.

7. Defects of the cell.—In every cell in which there is employed one fluid (dilute sulphuric) and two metals (zinc being the active one) the *current becomes feeble* after a certain time owing to the causes mentioned below. **(1) Local action.**—When the impure zinc of commerce is dipped into the acid, a current is *set up on the surface of the* metal itself and it is dissolved. This is called the *local action* and the current is called the local current. The *local action may be easily explained*: The impurities (chiefly consisting of iron, arsenic &c.) on the surface of zinc in contact with the acid play the same part as the copper plate does in the battery *i.e.*, the particle of the impurity and that of zinc form a couple, and a current is produced on the surface of zinc which exhausts or corrodes the metal.

Its remedy.—This is remedied by **amalgamating** the zinc surface with mercury. This allows a much stronger acid to be used for charging the cell.

The amalgamating process consists in dipping the surface in an acid (viz. nitric HNO_3) to clean it, and then a few drops of mercury is sprinkled over the surface and rubbed over it with a bit of linen rag tied to a stick. Mercury unites with the zinc at the surface. The iron particles are not dissolved by mercury and float up to the surface. The amalgamated zinc plate is not acted on by the acid when the circuit is open, but when it is closed the acid acts upon the zinc in the amalgam, the mercury then unites with the zinc in the next layer and forms a fresh layer of an amalgam, so the surface always remains covered with the amalgam.

(2). **The second defect. Polarisation and its effects.**—When a cell is set to produce a current it is observed that the *strength of the current falls off after a certain time.* This is due to the polarisation of the cell *i.e.*, *owing to the hydrogen bubbles produced on the surface of the copper plate sticking to it*, so as to form the surface layer.

The film of hydrogen *affects the strength of* the current in *two ways.*

(*a*). It weakens the current by *increasing the resistance* to the flow (gas being a non-conductor) and *also by decreasing the surface* of the metal *in contact* with the acid (since the gas bubbles prevent the acid from coming in contact with the metal).

(*b*). A *current is set up in a contrary direction to the principal current*, because the surface of copper being covered with a layer of hydrogen, the cell no longer consists of zinc and copper but hydrogen and zinc, and *hydrogen being more active than zinc, a current is produced,* the direction of which within the liquid is from hydrogen to zinc ; this is called the **secondary current**.

(Also *hydrogen* on copper plate *acts on the zinc sulphate* that is produced and *zinc is deposited on the copper plate*). The result is instead of copper and zinc *there will be ultimately zinc and zinc,* and so the current will be weaker and weaker till it stops.

Remedies—Means that are employed to reduce or prevent the polarisation of the cells are (1). **Mechanical means** in which *either hydrogen bubbles are brushed away* from the surface of the metal, or they are allowed to pass off to the surface of the liquid, either by keeping the liquid in constant circulation by siphons, or by making the surface rough or covered with points, so that the bubbles are collected at the points and are carried up to the surface.

(2) *Chemical means* in which *the negative plate is placed in a highly oxidizing substance* (such as bichromate of potash, bleaching powder, nitric acid) which destroys the hydrogen as it is formed (therefore in some cells platinum or carbon plates are are placed in nitric acid). These substances must not be used with *copper plate* (for it is acted on by them).

(3) *Electro-chemical means.* It entirely obviates polarisation it is adopted in many two fluid constant batteries, in which each cell is composed of two vessels one placed within the other and liquids are so selected that instead of hydrogen gas some solid substance (*i. e.*, the metal of the same kind) is deposited on the negative plate.

(3) The **third defect** of the cell is the **neutralisation of the acid**. It is found that the sulphuric acid is neutralised, so the chemical action ceases. To keep the current steady *acid must be renewed.*

8. Constant cells.—They are those *in* which the strength *of the current remains steady for* a long time. In order to make the cell constant it is essential *to prevent the polarisation of the negative metal.* This is effected by adopting the second and third means described above.

Single-fluid cells.—Wollaston's cell. It consists of a glass vessel which contains the acidulated water, a thick plate of zinc, and a plate of copper bent round so as to approach the zinc on both sides, thus diminishing the resistance. In this *polarisation is prevented by simply taking the plates away and brushing them.* For this purpose these bits are attached to a piece of board by means of a copper strip soldered at the end of each plate. In order to arrange them in a battery the copper strip of the zinc plate of one cell is connected with the copper strip of the copper plate of the next.

In *Smee's cell* polarisation is prevented by using platinised silver plate, the surface of which being rough gases are collected at different points and thus easily rise to the surface of the liquid.

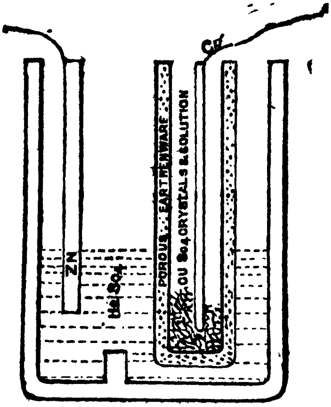
Bichromate cell consisting of zinc and carbon plates dipped in a solution of sulphuric acid and bichromate of potash, is *the only single fluid cell free from polarisation.* The hydrogen that is formed combines with the oxygen given off by the bichromate of potash and ultimately zinc sulphate and chrome alum are formed. The latter gives a green colour to the liquid after the cell has been in action. As the zinc plate is acted on by the solution when the cell is not being worked the plate is drawn out of the solution by means of a rod to which the plate is attached.

9. Two fluid cells.—In these each cell is made up of two vessels, one placed within the other, and the inner one is *porous* ; two different liquids are placed in these two vessels and the two metals used in the cell are placed in these liquids, one in each. The *one liquid is used* to act chemically on one plate so as *to generate electricity ; the other* is used *to prevent polarisation.* Complete *depolarisation* is effected in these cells.

(1). Daniell's cell.—In this, in one vessel (generally in the outer one) staturated solution of copper sulphate is placed and the copper plate is dipped in it. Within the other vessel common salt or dilute sulphuric acid is introduced, and the amalgamated zinc is dipped. The chemical action that takes place may be represented by the following equations.

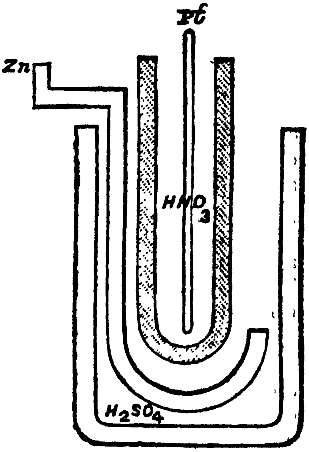
(*a*). In the outer vessel, $Zn + H_2SO_4 = Zn\,SO_4 + H_2$ (zinc and sulphuric acid produce zinc sulphate aud hydrogen gas). Then this hydrogen passes through the porous vessel and acts upon the copper sulphate in the inner one.

(*b*). In the inner cell, $H_2 + Cu\ SO_4 = H_2SO_4 + Cu$. (Hydrogen and copper sulphate give sulphuric acid and copper), and as copper plate is dipped in this solution copper is deposited on it. There is no polarisation then and also the acid remains unaltered, since the quantity neutralised by zinc in the outer cell s replaced by the acid formed in he vessel containing copper sulphate solution. Only copper sulphate is to be added to the solution in the inner vessel in order to keep it constant. This is effected by a perforated shelf at the upper part of the vessel below the level of the solution. In this crystals of copper sulphate are placed so that as the solution gets weaker a fresh quantity of the salt is dissolved. It *gives a constant though low current.* The acid that is used consists of one part by weight of the acid to twelve parts of water.



(2). **Bunsen's cell.**—In this cell copper and copper sulphate are replaced by carbon and nitric acid. The carbon plate or rod that is used is prepared from that deposited in gas retorts. It is a good conductor, and is dipped into the nitric acid and zinc in dilute sulphuric acid

(3). **Grove's cell.**—It is the same as the Bunsen's, only instead of carbon *platinum* strips are used. It is placed in nitric acid. In these two kinds of cells hydrogen, produced by the action of zinc on sulphuric acid, and liberated on carbon or platinum surface acts upon the nitric acid and converts it into water and one or more compounds of N and O, which are soluble in water and nitric acid to a large extent; but the continued working causes them to be evolved in the form of red fumes. According to some hyponitrous acid is formed, then the reactions are :—(*a*) $Zn + H_2SO_4 = Zn\ SO_4 + H_2$; $2\ H_2$ (hydrogen) $+ HN\ O_3$ (nitric acid) $= HNO$ (hy.



ponitrous acid) + H_2O (water). This is dissolved in water and is subsequently disengaged as nitrous fumes.

4. Leclanche's cell.—In this zinc rod is placed in the solution of salammoniac and to prevent polarisation the carbon rod is placed in the porous pot, which is tightly packed with powdered pyrolusite (oxide of manganese MnO_2) and carbon. Pyrolusite gives off oxygen which destroys hydrogen. *It gives a constant current and is used for domestic purposes* (ringing the bells &c).

$$Zn + 2\,NH_4\,Cl = Zn\,Cl_2 + H_2 + 2NH_3$$

Zinc and Salammoniac yield zinc chloride, hydrogen and ammonia. This hydrogen takes up oxygen from the pyrolusite and is converted into water. While the peroxide is converted into a lower one (probably Mn_2O_3)

Advantages and disadvantages of different kinds of cells.—

The current given by a Daniell's cell (EMF 1 to 1·14) is low, but it remains nearly constant for some hours. It does not give up noxious nitrous fumes.

Bunsen's (EMF 1·75 to 1·96) and grove's (EMF 1·92 to 1·95) cells give strong currents. The electromotive force of the former is generally a *little greater* than that of the latter. The former differs from the latter only in the substitution of gas graphite for platinum in the porous cells. This diminishes the cost of the cell, but makes it less compact. On account of the porous texture of carbon, it is troublesome to keep it in order, and there is some difficulty in making a good contact between the rough surface and the copper strip. It is also less cleanly to work with. Both of them give out noxious nitrous fumes.

The strength of the current in the Leclanche's cell is feebler than that of a Daniell ; the current remains constant for a long time : It does not require renewing for months or years, for when left at rest it can quickly regain its original strength, but it is not suited for continuous work. Bichromate cell (EMF = 2) is not suited for long continued work, but it gives powerful effects, when used for a few minutes a time.—It is portable and free from noxious fumes of nitrogen.

A *good voltaic cell should fulfil* all or most of the following *conditions*—

(1) Its electromotive force should be high and constant.
(2) Its internal resistance should be small.
(3) It should give a constant current *i.e.*, should be free from all the defects of ordinary cells *e.g.*, polarisation. local action &c.
(4) It should be perfectly quiescent when the circuit is open.
(5) It should be cheap and of durable materials.
(6) It should not emit, if possible, noxious fumes. It should also be manageable.

10. The effects of the currents of electricity in Voltaic batteries.—They are identical with those of Frictional Electricity (in Leyden jar batteries) the difference is that in Leyden jar the discharge is instantaneous, whereas it is continuous in Voltaic battery. Its **physiological effects** consist of shocks and violent contraction of muscles that take place, when any living or dead body to be experimented upon is connected on one side with the positive, and on the other side with the negative pole of the Voltaic battery.

The heating effects of the Voltaic current are observed when the wire connecting the two poles of the Voltaic battery is very thin. It becomes heated and incandescent, when traversed by the current. By means of the battery substances that were considered refractory have been fused. *The* **luminous effects** of the battery are obtained when the two poles are brought very nearly in contact; a continuous succession of bright sparks passes across the interval. Electric light is produced by placing two sharp pointed carbon pencils at the ends of a battery and then bringing the points in contact with one another, when the carbon points become incandescent.

Chemical effects of the current. Electrolysis.—Chemical actions (decomposition and recombination) are produced when any current is made to pass through certain liquids. *This process of decomposing liquids by means of an electric current is* called **electrolysis**, and the bodies which can be thus decomposed are called *electrolytes*. By means of this method of analysis (or electrolysis) many bodies hitherto regarded as elements have been decomposed and their compound nature revealed. In 1808 Davy succeeded in decomposing potash and soda, up to that time considered as elements. It may be shown by taking a large piece of caustic potash in which a cavity is made, mercury is introduced into this cavity and the positive pole of the battery is connected with potash block and the negative pole is dipped into the mercury. Oxygen is liberated at the positive pole and potassium liberated at the negative pole amalgamating with mercury. On heating the amalgam mercury passes away in vapour leaving potassium behind. The decomposition of all binary compounds is effected in this manner. The body found at the *positive* pole is called *electronegative*, that at the *negative pole* is *electropositive*. The same body may be electronegative or electropositive according to the body with which it is associated.

11. Electrolysis of water.—In 1808 Carlile and Nicholson first discovered that a Voltaic current could be passed through water and that in passing through it water was decomposed into its constituent gases. The apparatus that is now-a-days used for the purpose, consists of a glass vessel fixed on an insulating support. Into the bottom of the vessel two platinnm strips are fitted, communicating by means of copper wires with water to which a little acid has been added to increase its conductivity, two glass tubes filled with water are inverted over the electrodes and on connecting the two screws with the two poles of the battery, decomposition sets in and gas bubbles rise from the poles and are collected in the tubes.

12. Laws of electrolysis.—These are (1). *Electrolysis cannot take place unless the electrolyte is a liquid conductor* ; (2). The *energy* of the electrolytic action of the current is the *same* in *all* its *parts*, (3). The *same current decomposes* chemically *equivalent* quantities of the *bodies* which it traverses (4). The *quantity* of a body decomposed in a given time is *proportional* to the *strength of the current*. Faraday discovered these laws.

13. Grothuss hypothesis.—Assuming that every binary compound (or a body acting as such) consists of two elements (or groups) an electropositive and an electronegative, he states that under the influence of the contrary electricities of the electrodes, a series of successive decomposition and recombination are effected from one pole to the other. Hence it is only the elements of the terminal molecules that do not recombine, and remaining free appear at the electrodes:

Objections.—Clausius has pointed out that on this theory there ought to be no decomposition and no current as long as the electromotive force is below a certain value (*i.e.*, less than the force of affinity for each other of the oppositely electrified particles of the compound) but that as soon as it has reached this value a vigorous decomposition ought to commence accompanied by a strong current. This is by no means the case, for the current is proportional to the electromotive force for all the values of that force and the *quantity decomposed is proportional to the strength of the current.* Also Buff has shown that the action of the *feeblest current produces decomposition.*

Clausiu's theory.—To meet this difficulty he applies his dynamical theory of molecules and states that molecular agitation is sometimes so violent that compound molecules are split up into their constituents. These constituent atoms knock about and *meeting other atoms of the opposite kind, form* new molecules of the compound. In every compound then the particles *are in a perpetual state of separation and reunion, so that compound molecules and their elementary constituents co-exist together in a body. Hence* the *current does not bring about the decomposition, but it gives definite directions to the separated constituent molecules* in their intervals of freedom (so that they are deflected from the path they would otherwise have followed).

14. Applications of the principles of electricity to arts. Electrotyping.—It is the *process of producing exact* copper or other *metal copies of articles by* means of *electric current.* It consists of two distinct operations.

First, the preparation of the mould or the impression of the object to be reproduced. Various bodies are used for taking impressions, but wax and gutta percha are chiefly employed. A plate is prepared of wax or gutta percha (in case of the latter it is to be placed in warm water to make it soft). It is then brushed over with graphite (or black powder) to make the surface a conducting one. Then the object to be copied is pressed against the plate, care must be taken to make the pressure uniform throughout the surface. The mould that is obtained is hollow and inverted *i.e.*, the copy is *in intaglio*. The mould is now ready to be deposited upon.

The *second* operation which now begins is the deposition of metals on the mould. A bath is prepared containing the solution of the metal to be deposited upon. In order to take copper cast the bath is filled with a solution of copper sulphate, two copper rods are placed across the bath but insulated from it, one is connected with the negative and the other with the positive pole of the Daniell's element that is generally used. The mould is suspended by metal wires from the rod connected with the negative pole, and a copper plate is suspended in front of the mould from the rod connected with the positive pole. The current being closed the mould is covered with the deposit of a thin layer of copper. When the deposit is sufficiently thick it can be separated from the mould by heating it a little. A portion of the copper plate in connection with the positive pole is dissolved in the solution so that its strength remains constant for a long time.

a. **Electroplating.**—The **old method of gilding** or silvering was to apply an amalgam of gold or silver and mercury on the article to be gilt or silvered. It was then heated in a furnace, mercury passed away as vapour and the gold or silver remained in a very thin layer on the object. This process was expensive and unhealthy; it has been replaced by the *modern* **method of electroplating**. It is the *process of giving a permanent metal coating to objects made of metal by means of an electric current.*

The most important thing in the process, upon which the success depends is the preparation of articles before plating them with any metal. The surfaces must be made *chemically clean*, ordinary cleanliness is of no importance. The surfaces of the article to be dipped in the solution are cleaned off by rinsing it in boiling caustic potash solution, in dilute nitric acid, and dipping it in different cleaning mixtures varying according to the nature of the articles ; (*silver* articles being *dipped* in for a moment in strong *nitric acid* ; *copper*, german *silver* and brass articles, in a mixture of ½ gal. water, ½ gal *sulphuric acid*, 1 qt. *nitric acid*, and 2 ounces *muriatic acid*). The article is then swilled in water and dipped in the bath.

In *electrogilding* and *silvering*, the *bath* is an *alkaline solution of gold and silver* (*i.e.*, a *solution of cyanide* of gold or silver and potassium). The bath is prepared by suspending in the solution of cyanide of potassium two plates of gold or silver, one larger, from the positive pole, and the other smaller from the negative pole of the battery. A portion of gold or silver is thus dissolved away and remains in the solution. When the solution acquires sufficient strength, the object to be coated is placed opposite this, connected with the positive pole.

The article that is often used is made of copper. silver, bronze or german silver. If it is made of any other metal such as iron, zinc, tin &c., it must first be coated with copper by placing it in a copper sulphate solution as in electrotyping ; then it is placed in the solution of the metal to be coated with. This method is now-a-days used to *steel* engraved copper plates. For this purpose the bath is prepared by suspending a large steel plate from the positive pole of the battery in *the bath of salammoniac solution* ; a thin strip of iron being placed in connection with the negative pole. A portion of iron dissolves away and remains in the solution and when the bath acquires sufficient strength, the small strip is taken away and is replaced by the copper plate.

15. Ohm's law —Ohm founded the important law, which bears his name, that the *strength of the current varies directly as* the *electromotive force* and *inversely* as the (total) *resistance* of *the circuit* ; or by selecting proper units it may be stated that $C = \frac{E}{R}$. The *intensity* or *strength of the current* is *the quantity of electricity which flows through any section of the wire in unit of time*. *Electromotive force* is the force by which electricity is set in motion in the Voltaic circuit. The *resistance of the circuit* is that of all the parts of which the circuit is made, *viz.*, the resistance of the zinc plate, the liquid, the copper plate and the wire. By means of the galvanometer he found *that the strength is the same in all the parts of the circuit*, for *the needle is deflected to the same extent* over whatever part of the circuit it is suspended or wherever the galvanometer is placed.

The *strength of the current* in a cell *may be increased* in two ways :—

(1) By increasing its E. M. F.

(2) By diminishing its internal resistance.

The internal resistance of a cell may be diminished by (*a*) bringing the plates nearer together ; (*b*) increasing the size of the plates.

The laws of resistance.—(1). The *resistance* of a conducting wire of given length and thickness *depends upon* the *material* of which it is made ;

(II). The *resistance is inversely proportional* to the *area* of the cross section, and consequently to the *square of the diameter*, of the wire ;

(III). The *resistance* is *directly proportional* to the *length* of the wire.

In order to prove these laws he connected one end of a constant cell with one of the binding screws of a galvanometer. the other end dips into a mercury cup ; a wire from the other binding screw dips into another mercury cup. By interposing *wires* of the same length and the same diameter but of *different materials* between these cups in the circuit, the needle is found to be *deflected differently* proving that the *resistance* of a body depends upon its *nature*. Again by connecting the cups by *different lengths* of the *same wire*, the deflection is found to vary, shewing that *resistance increases with the length*. Also by placing wires of the same length and the same material but of *different diameters*, the needle is found to be deflected differently showing that *resistance* varies inversely as the *cross section* or the *square* of the *diameter*.

The copper is the best conductor of electricity. Liquids have greater resistance than metals. The resistance of metals increases with the temperature whereas that of liquids diminishes with the rising of temperature.

QUESTIONS.

1. What is current electricity and how is it produced ? (1). What are the different theories regarding the production of this kind of electricity ? State fully the *contact-theory* and the experiments made to support the theory ? (3). How far is the theory tenable and what are the objections that were brought against it ? (4).

2. Explain clearly the chemical action that takes place in the Volta's cell, when the current is generated (5). Define :—electrode, negative plate, electromotive force, polarisation and local action (6,). What are the chief defects in the cell and how may they be remedied ? (7).

a. State fully the *thermal*, *Electrical* and *chemical* conditions of a cell when the plates are (i) not joined (2) joined by a thin wire. (6)

3. How is the current kept constant in a *single fluid* cell ? (8) Describe the construction of a Daniell's, Bunsen's or a Leclanche's cell (9). What is the method that is adopted in these cells to make the current steady and uniform ? (9). State fully the advantages and disadvantages of different kinds of cells. (8)

4. Describe some experiments to prove the effects of current electricity (10). Describe the process called *electrolysis* (10). How is water analysed in this method ? (11). What are the laws of electrolysis and the hypotheses lpgarding it ? (12)„ (13) Describe the processes of *electrotyping* (14) and *electroreating* (14*a*).

5. What is *Ohm's law* ? How can you prove this law and the *laws* of *resistance* experimentally ? (15).

MAGNETIC EFFECTS OF THE CURRENT.

1. Relation between magnetism and electricity.—Points of resemblance, that were observed early between magnetism and electricity, are that like kinds of electricity repel one another as also do like kinds of magnetism and that unlike kinds of both attract each other. Electricity induces electricity in conductors so also does magnetism induce magnetism on magnetic bodies. Dissimilarities that were observed are, that a magnet placed in contact with the earth does not lose its magnetism as does an electrified body ; and that electricity can be produced in all bodies, while magnetism is manifested by a very small number. Lightning magnetises knives and in striking a ship it reverses the polarity of the compass and sometimes destroys it.

2. Oersted's experiments.—In 1813 he discovered the close connection between electricity and magnetism, and found that electric currents have a *directive action upon the magnetic needle and always tend to set it at right angles to their own direction.* To shew this a straight wire traversed by a current is to be placed parallel to and near a magnetic needle movable upon a pivot, the needle will be deflected and will come to rest making a certain angle with the wire.

Ampere's rule.—The **rule** as laid down by **Ampere** is that the *north pole is always deflected towards the left of the current, i.e., if a man swims in the wire with the current, with his face turned towards the needle, he sees the north pole of the needle deflected towards his left hand.*

This *action between an electric current and a magnet is mutual i.e.,* just as currents act on magnets *so do magnets on currents.* Therefore if a magnetic *pole be fixed and the circuit movable, the latter will set transversely to the length of the bar.* The rule is that a man swimming in the wire with the current and looking along the lines of force, (*i.e.*, away from the pole when it is north and towards the pole when it is south pole) will be urged by a force towards his left. *To prove this a circle* of copper wire *provided with steel* points is taken. These two points dip in two mercury cups at the ends of two metal rods attached to two vertical metal stands, so that the circle can move freely in any direction. When these two stands are connected by binding screws with the two poles of a battery, the current passes through the circle. If now a magnet be placed beneath the circle but in its plane, the circuit will set transversely to the length of the bar.

3. The earth being a huge magnet exerts a directive action on the movable circuit.—If in the above experiment the circle is first placed in the magnetic meridian, as soon as the current passes through the circuit it places itself transversely to the first position. The *direction of* the current *in the lower part is from east to west.* From Oersted's experiment it is clear that if a *magnetic needle* suspended by a silk thread *is placed within a rectangular circuit, the action of the current* on the north pole of the needle *will be increased* almost four-fold; for the four portions of the current occupying the four branches of the rectangular circuit tend to deflect the north pole towards the same direction. Now the effect of the current is increased four times by one rectangle, *i.e.*, by one turn of the circuit. The *effect is* then *increased with the number of turns.*

Astatic system—The *directive action of the earth* continually tends to keep the needle in the magnetic meridian, and thus opposes the action of the currents (in the above case). The effect of the current is increased by using an **astatic system,** *consisting of two needles, of nearly equal strength and size, and rigidly connected together in reversed positions.* This system is *unaffected by the earth's magnetism,* for the action on the one needle is counterbalanced by that on the other. *If one of the needles* in the system *be placed within the circuit and the other above it,* it is *readily deflected* by a current flowing in the circuit, *for the current* which flows above the one needle and below the other will, *according to Ampere's rule* given above, *urges both in the same direction,* since they are in reversed positions.

A galvanometer with an astatic system is more delicate, since the needle is not affected by Earth's magnetism and consequently a very feeble current can cause its deflection.

Galvanometer.—Schweigger *constructed a* **galvanometer** *on this principle.* It consists of a brass plate resting on levelling screws; on this is placed a *hollow copper frame on which is coiled a number of turns of wire covered with silk,* the two ends terminating in binding screws. *There is a central slit parallel to the direction in which the wire is coiled. Above the frame is a graduated disc* with a central slit. By means of a silk thread *an astatic system is suspended, one of the needles remaining above the* *disc.* By means of this instrument the presence of a very feeble current can be measured from the angle through which the needle is deflected when the two poles of a battery are connected with the two binding screws.

4. **Tangent galvanometer.**—It is an apparatus to determine the strength of the current which is proportional to the *tangent* of the angle through which the needle is deflected. It consists of a circular coil made of a few turns of stout copper wire. At the centre is delicately suspended a small magnetic needle furnished with a light index. The essential point of this is, that the needle should be very small compared with the diameter of the circle, so that its poles are never far from the centre, at which point only the magnetic force of the current is uniform. The instrument is adjusted by setting the coil in the magnetic meridian, the needle then lying in the plane of the coil. As soon as the current passes through the coil the needle is deflected and is found stationary at a certain angle (θ suppose) with the meridian. At that point the forces acting on the poles are one (E), parallel to the magnetic meridian due to Earth's magnetism, and the other (k. i.), perpendicular to the meridian, due to the current (i) in the coil; since there is now no rotatory motion in the needle, the component of E perpendicular to the needle (E Sin θ) is equal and opposite to that of i. k. in that direction. (i.k. cos θ) ; (or taking the moment of these forces about the pivot of the needle) we get $E \sin \theta = i.\ k \cos \theta \therefore i = \frac{E}{K} \tan \theta$

5. **Magnetisation by Electric currents.**—Arago found that if a current be passed through a piece of copper wire it becomes capable of attracting iron filings to it. These filings set themselves at right angles to the wire and cling round it, but drop off when the current ceases. This shows that there is a magnetic field around the wire traversed by a current. *Ampere* performed an experiment to *show* that *electric currents by acting upon magnetic bodies separate the two magnetisms.* The apparatus consists of an insulated copper wire coiled round an unmagnetised steel or iron bar. When a current is made to pass through the wire by connecting the two ends with the poles of a battery the bar is magnetised. If a Leyden Jar be discharged through the spiral by connecting the two ends with the two coatings of the jar the bar is also magnetised. In case of steel, magnetisation is permanent, though it is temporary in soft iron. By applying Ampere's rule the poles of the electromagnets can be easily determined. For imagine a man swimming along the current with his face towards the centre where the bar is, the north pole will be towards his left. The relation may be stated thus :—

A person looking towards the **south-pole** *will observe the current to circulate round in the direction of the hands of a watch,* *i.e.*, **clock-wise** *and one looking towards the* **north-pole** *will have the current circulated in the direction opposite to the hands of a watch or* **counter-clock-wise**.

6. Action of currents upon currents.—Ampere discovered that *a current* not only *acts* upon magnetic bodies but *upon other currents also*, attracting or repelling them according to the following laws.

1. *Two parallel portions of a circuit attract one another if the currents in them are flowing in the same direction, and repel one another* if the *currents flow in opposite directions.*

2. Two *portions of a circuit crossing one another obliquely attract one another if both* the currents *run* either *towards* or *from* the *point* of crossing ; and *repel one* another if the *one runs to* and the *other from* that point. This is also called the *law of angular currents.*

Experiments.—To prove these laws an apparatus is taken consisting of a wooden board on which are fixed two vertical metal stands joined at their tops by a wooden crosspiece. In the centre of this cross piece is a binding screw and below this is a mercury cup provided with an iron pivot ; a rectangular copper coil is placed with its one end on this pivot, the other end being placed on a pivot in another mercury cup placed on the board. This latter cup is connected by a metal strip with one of the rods and the binding screw on the crosspiece with the other rod. *To prove the first part of the first law* two rods are joined to the poles of a battery in such a way that the direction of the currents in the rods is the same as that in the two sides of the rectangular circuit placed parallel to them. *To prove the second part* the direction of the current on the rods must be opposite to that on the sides of the circuit.

6. *a.* **Proof of the 2nd law, Roget's Vibrating Spiral**.—The second law may be proved by placing the circuit *obliquely* to the rods. It may also be deduced from the first law by resolving the two oblique currents into two pairs of parallel currents at right angles to one another ; the attraction of like parallel currents is illustrated by **Roget's Dancing Spiral**. It consists of a copper spiral fixed at one end to a binding screw attached to a metal stand. The other end of the spiral just grazes the surface of mercury in a cup, placed on a metal support and provided with a binding screw. When a current passes through the spiral, it begins to oscillate up and down, for the *current* in *each* coil being like and parallel to that in the other, attracts one another, the spiral becomes shorter and the end of the spiral rises above the surface of the mercury in the cup, the connection is cut off and the current ceases. The coils being no longer attracted the spiral resumes its length and the end again touches the surface of the mercury, the current passes again and it becomes shorter. This process is repeated and the spiral dances as it were.

7. It has been said that a *current* passing through a straight wire has a *magnetic field around* it. Also from Ampere's rule it is known that when a current passes through a wire its tendency is to urge the north pole round it towards the left of the current, so that the pole will tend to move in the direction of the hands of a watch, consequently the south pole will move in the opposite direction.

This can be proved by passing a wire traversed by a current through a card placed horizontally and sprinkling iron filings on the latter; filings near the wire will set themselves in concentric circles round it.

If instead of a straight wire a loop is made by the wire traversed by the current, it is easily seen from what is said above that the space enclosed by the loop possesses magnetic properties. If the current is flowing round the loop in the direction of the hands of a watch and if the circuit is in the plane of the paper a man swimming along the current with his face towards the centre would have his left side down. By Ampere's rule then the *north pole* of a magnet will be *attracted downwards* through the loop. And as the north pole is attracted by the south pole and repelled by the north pole; therefore the space enclosed by the loop *behaves like a magnetic shell*, with its upper face exhibiting South magnetism and the lower one North magnetism. *A circuit is thus* seen to be *equivalent to a magnetic shell, whose edges coincide with the circuit.* It acts on a magnet attracting or repelling it and is also acted upon by the magnet.

Solenoid.—Instead of a single coil if a *solenoid*, *i.e.*, a helix consisting of a number of equal and parallel circular currents made up of the same piece of covered copper wire, is taken, it will act as a magnet whose **area** is that of the coil and length that of the helix. The rule shows first that a solenoidal *helix* can behave like a magnet on another magnet; second that two solenoids can mutually behave like two magnets.

De La Rive's floating battery.—The first is proved by *De La Rive's floating battery*, it consists of a copper wire solenoid the ends of which pass through a piece of cork and are soldered, one to a plate of zinc and the other to a plate of copper. If this is floated on the vessel of acidulated water a current will pass through the solenoid which will ultimately set itself north and south. The north pole of a magnet will be attracted when it is brought near one end of the solenoid and repelled by the other. If a person looking towards one end of the solenoid sees the current passing in the direction of the hands of a watch that end of the solenoid will correspond to the south pole of the magnet ; the other end in which the direction is opposite to the hands of a watch behaves like the north pole.

Similary if a *solenoid is brought near another movable* solenoid the latter *will be attracted* or *repelled according to the end presented.* From Ampere's law of mutual action it is easily seen that *if the currents in the ends* brought together be in *the same* direction, *they will attract* one another, if in *opposite* directions *they will repel one another.*

8. Ampere's Theory of Magnetism.—Observing the analogy between magnets and solenoids, Ampere advanced a theory of magnetism based on the Electrodynamic principle. He has assumed that each individual molecule of a magnetic body is traversed by a closed electric current ; that when the substance is not magnetised, these molecular currents, under the influence of mutual attraction, neutralise one another ; that magnetisation consists in giving these currents a parallel direction, and the stronger the magnetising force, the more the parallelism The limit of magnetisation is obtained when the currents are completely parallel. The resultant action of all these molecular currents is equivalent to a single current traversing the outside of a magnet, for at every point within the magnet there are two equal and opposite currents ; since molecules are lying side by side, and the current in the one at any point is opposite to that in the neighbouring molecule. From experiments on solenoids it has been already determined that the direction of the current at the north pole is *opposite* to the motion of the hands of a watch ; and that at the south pole is the *same* as the motion of the hands of a watch.

9. Earth's magnetism explained by the theory.—The magnetism of the Earth can be explained by this theory by assuming that the surface of the globe is traversed by currents from *east to west*, the resultant of which is a single current along the magnetic Equator. These currents are thermo-electric, due to the unequal heating of the different parts of the Earth's surface (from various causes) and variation of temperature caused by it.

9. *a* Solenoids and magnets compared.—From Ampere's theory it is easily seen that a solenoid is *complete* only when *a part of the wire passes through the helix in the direction of the axis, so that the direction of the current there,* is *opposite* to that in the coil. For the theory supposes that the surface of a magnet is traversed by a series of parallel currents (all independent of one another); but *in the solenoid the same current is made to pass through the spires from one end* of the helix to the other. Now each spire of the helix represents a *circle perpendicular to the axis* together with a *straight portion parallel* to the axis and *equal* to the *distance between* the *two spires.* The effects of all the straight portions is exactly destroyed by the *return wire,* so that only the *parallel circular* currents will have effect. Then the solenoid resembles a magnet in its external effect.

10. Electromagnets.—They are bars of soft iron, which under the influence of an electric current become magnets. The coercive power of soft iron being very small, the magnetism ceases when the current is stopped. The most convenient and useful form of electromagnet is that of a horse-shoe in which both the poles may be applied to one armature. Instead of one piece it may consist of two cylinders screwed to a cross-piece of the same metal. The coils are generally divided into two equal parts wound near the poles. The great usefulness of the electromagnet, in its application to electric bells and telegraphic instruments, lies in the fact that its *magnetism is entirely under the control of the current.* The *force of an electromagnet depends* on its *dimensions,* on the *number of turns of the wire,* and on *the strength of the current.*

11. Electric Telegraphy: History—It is difficult to assign the invention of the Telegraph to any particular inventor. Many philosophers proposed to correspond at a distance by means of the effects produced by an electric current passing through an insulated conducting wire. In 1811 Sœmmering invented a telegraph in which signals were made by the decomposition of water in voltameters. Ampere proposed to correspond by means of wires and magnetic needles; as many different wires and needles being used as letters were required. Gauss and Weber constructed an electromagnetic telegraph, the oscillations of the bars served as signals. • Cooke and Wheatstone first brought into application the needle telegraph.

Every telegraph consists of three essential parts (1) an *Electromotor* producing the current and a *circuit*, connecting two places by a metal wire (2) a *communicator* for sending the signals *from* one station, and (3) an *indicator* for receiving them at the other station.

There are three principal systems of telegraph, *viz.*, the needle telegraph, the dial telegraph, and the printing telegraph.

12. The Morse's Instrument.—This is *based on the temporary magnetisation and demagnetisation of soft iron by the passage of intermittent currents.* It consists essentially of an electromagnet, which, when a current passes through its coils, draws down an armature for a short or a long time. It may be arranged to print dots and dashes upon a strip of paper drawn by clockwork through the instrument. It may also be used as a *sounder* in which case the man receiving the message must accustom his ears to the clicks and notice whether the intervals between them are long or short.

An electromagnet is fixed at one place, the insulated wires of which are attached to the two binding screws. Above the magnet is a lever movable about a vertical axis and ending in an armature of soft iron which is drawn up by a spring; whenever the magnet is traversed by a current the armature is drawn down, and the other end of the lever raised. To this end is attached a pin or a pencil which presses against the paper; everytime the end is raised (*i.e.*, the armature is attracted) *dots* are marked when the point touches the paper for a moment only; *dashes* are marked when the point remains in contact with the paper for a time. Two metal wires connect the two binding screws of the electromagnet with the poles of a battery at another place. The circuit being closed the electromagnet will attract the armature. If a person sitting at the battery breaks the contact, the armature resumes its original position; again when the contact is made the armature is attracted. Thus a person from one place can cause a lever to oscillate at another place, as often as he pleases. Two stations are communicated by wires called *Line Wires.* The earth being a good conductor has been used to serve the purpose of the *return conductor.* In this case there is one wire connecting the positive pole of the battery with a binding screw of the Electromagnet. A copper plate conn ected with the negative pole by a copper wire is either sunk in the Earth or placed in a deep well. The other binding screw of the Electromagnet is connected with the earth by a wire and plate. A current passes from the battery, traverses the coil of the magnet, and then enters into the Earth through the binding screw. It then emerges again through the wire connected with the negative pole and returns to the battery. (Thus the message is sent by one line and the earth is used as the return line.)

13. Voltaic and fractional electricity.—There is *no* *difference* whatever *in kind* between the electricity produced by friction and that produced by chemical action, in the effects of tension and in induction towards the surrounding objects, in the polar character of its action and in the opposite nature of the electricities accumulated at the extremities of the apparatus. In each case electricity requires for its production the *contact* of dissimilar materials, and the *amounts* of the two electricities produced are *equal.* In the one, electricity is produced by the friction between two bodies (generally insulators) and in the other it is produced by the difference of the chemical action of the liquid on the two metals. *The quantity* of electricities *produced by friction is* comparatively *small but their tensions are very high, whereas in voltaic elements greater amount* of electricity *is produced but its tension is low.* For instance if one of the poles of the battery be joined with one of the discs of a delicate Volta's electroscope, (the other disc being connected with the Earth, the leaves will diverge *a little* when the upper disc is taken away, but if electricity is produced by friction on the disc, there will be a greater divergence. Again a feeble current of Voltaic electricity causes deflection of the magnetic needle, but it is very difficult to effect a deflection of the needle by the current produced by frictional electricity.

Any change in the distribution of statical electricity on the surfaces of bodies produces currents until the redistribution is completed. Thus a current is produced when the prime conductor of the frictional machine is connected by a thin wire with the earth or with a conductor. In the latter case the current ceases to flow when the tension of electricity in the conductor is the same as that on the machine.

14. Statical and dynamical electricity.—There are certain *effects* that are *peculiar to current electricity* only. Two conductors traversed by currents in the *same direction attract* one another, but *when they are traversed by the currents in the opposite direction they repel one another.* All these attractions and repulsions are wholly distinct from the attractions and repulsions between charges of electricity at rest. Again *mere electricity of tension*, or *electricity at rest* has *no influence* upon a *magnetised* bar, but a *current electricity deflects the magnetic needle in the direction* depending upon the direction of the current.

QUESTIONS.

1. Find out the points of similarity between magnetism and electricity. (1). Describe Oersted's experiment and state the results. (2). Prove that the Earth exerts influence on movable circuits traversed by currents (3). What is *astatic system* of needles ? (3). Explain the construction of the galvanometer and prove that the current varies as the *tangent* of the angle (3, 4).

2. Describe the experiment which proves that a current can magnetise magnetic bodies. What relation does the polarity of the magnet bear to the direction of the current ? (5).

3. Enunciate the laws which govern the mutual action of currents and prove them experimentally (6). Explain the working of the Roget's Dancing Spiral (6 a).

4. What is a solenoid ? Prove that it acts like a magnet. Describe De La Rive's floating battery. What does it prove ? (7).

5. State fully Ampere's theory of magnetism. (8). From this explain Earth's magnetism (9). Also prove from this that a solenoid *is complete only when it is provided with a return wire* (9 a).

6. What are electromagnets (10). Give a brief history of Telegraphy. What are the essential parts of a telegraph ? (11). Describe the construction of Morse's instrument. (12).

7. Compare the electricity produced by friction with that produced by Voltaic action. (13). State the chief points of difference between Statical and Dynamical electricity. (14).

INDUCTION BY ELECTRIC CURRENTS.

1. The term *induction* has already been defined as the action which an electrified body exerts at a distance on bodies (generally conductors) in the natural state. **Induced currents** are the *instantaneous currents produced in conductors by the influence of neighbouring currents or magnets.* In 1831 Faraday discovered that *currents can be induced* in a closed circuit *by moving magnets near it or by moving the circuit across the magnetic field.* He also proved that *a current whose strength is changing may induce a current in* a closed *circuit near it.*

2. Conditions of Induction by currents:—

1. The distance remaining the same a *continuous* and constant *current does not induce* any current in an adjacent conductor.

2. *When a current begins to flow* (at the moment the circuit is closed) *it induces an inverse current, but when it ceases it produces a direct current.*

3. A current, which is *removed* or *whose intensity is diminished*, gives *rise to a direct induced current*, when a current *approaches* or its *intensity* is *increased, it induces an inverse current.*

The *induced current* is said to be *direct* when its *direction* is the *same* as that of the inducing current ; and *inverse*, when the *direction* is opposite.

These laws may be summed up by the following *Lenz's law*—If the relative position of two conductors A and B be changed, of which A is traversed by a current, a current is induced in B in such a direction that by its electrodynamic action on the current in A it would have imparted to the conductors *a motion of the contrary kind* to that by which the inducing action is overcome.

3. Experimental proofs—These may be experimentally determined by taking a *primary coil* consiting of a hollow cylinder of wood or of cardboard round which stout silk-covered copper wires are coiled. This is surrounded by another hollow cardboard cylinder on which is coiled a long and very fine insulated copper wire. This is called the *secondary coil.* The two ends of the wire in the *primary coil* are connected with the two binding screws by which they may be connected with the poles of a battery. The ends of the wire in the secondary coil are attached to another pair of binding screws by which they may be connected with the galvanometer.

To prove the second law, one of the binding screws connected with the primary coil is joined to one pole of the battery. As soon as the wire connected with the other pole is joined to the other binding screw a current passes in the primary coil. At the same time the galvanometer connected with the secondary coil is found to be deflected in the direction opposite to that of the primary current. At the moment when the circuit is opened the primary current ceases and the galvanometer is deflected in the same direction.

To prove the third law—If the primary coil, while it is traversed by a current, is suddenly removed from the hollow cylinder of the secondary coil, or if some cells are suddenly disconnected from the battery so that the strength of the current is diminished, the galvanometer is seen to be deflected in the same direction. Again if the primary coil is suddenly replaced or the strength of the primary coil is suddenly increased the galvanometer is deflected in the opposite direction.

4. Induction by magnets and by the Earth's action.—When a pole of a *magnet* is introduced into the *centre of the primary coil*, an *inverse current* is *induced* in the secondary coil; when it is *withdrawn* a *direct current* is induced. If from the apparatus described above, the primary coil be removed; and into the hollow cylinder a magnet suddenly introduced, the galvanometer is deflected showing the presence of an induced current opposite to that which circulates round the magnet. Again if the magnet is suddenly removed a direct current is induced. The Earth being regarded as a huge magnet, must induce currents in conductors in motion. Faraday discovered this first and proved it by placing a helix in the plain of the magnetic meridian parallel to the dipping needle, and rotating it about an axis in its middle at right angles to its length. At each turn the galvanometer connected with the ends of the helix is seen to be deflected.

Table showing the *direction* and *cause* of the *momentary* currents *induced* in a circuit.—

DIRECTION	CAUSE.
Inverse	1. While a *magnet* is approaching. 2. While a *current* is (*a*) approaching, (*b*) beginning to flow, or (*c*) increasing in strength.
Direct	1. While a *magnet* is receding. 2. While a *current* is (*a*) receding, (*b*) ceasing to flow, or (*c*) decreasing in strength.

7. **Extra current.**—If two portions of the same wire lie side by side, the sudden commencement or cessation of a current in one portion induces a current in the other as if they were two unconnected circuits. This occurs whenever a current commences or ceases in a coil, each turn exercising an inductive influence on the rest. This action is called the *induction of a current on itself*, and the current due to it is called the *extra current*. The extra current at the *make* of the primary circuit is *inverse*, and merely acts as a hindrance to the commencement (it prevents the battery current from rising at once to its full value) but that on the *break* of the circuit is *direct* (and is powerful). Hence it is that a spark is obtained on breaking and not making the contact.

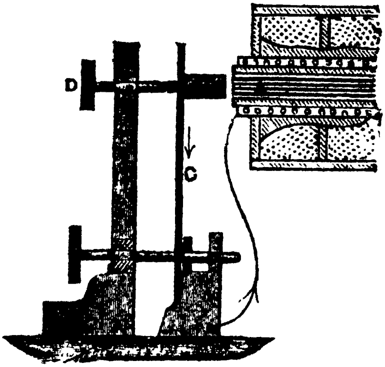
8. **Ruhmkorff's coil**—It is an instrument used to exhibit the effects of induced currents. It consists of a cylindrical bobbin having a central iron core surrounded by a coil of stout insulated wire called the primary coil; this coil is joined to

the poles of a battery and is enclosed in an insulating cylinder of glass or of ebonite. In it also are included an *interrupter* and a *commutator.* Another coil consisting of many thousand turns of very fine copper wire and very carefully insulated between its different parts is placed round the insulating cylinder (each individual coil is separated from the other by a layer of shellac). The *iron core* is generally made up of a number of soft iron wires, to prevent induction on the surface of the core, which counteracts the inductive action of the original current.

9. It has been already said that a current is induced by a voltaic current only at the time of *making* and *breaking* the contact; therefore the *interrupter* is inserted into the primary circuit. It is a self-acting arrangement, usually an oscillating hammer which alternately *makes* and *breaks* the (primary) circuit. The result of this is to induce, an *inverse* momentary current on the secondary circuit *at every make*, and a *powerful* momentary *direct* current *at every break.* The common form consists of a piece of thin steel which makes contact with a platinum point and which is drawn back by the attraction of the core on the passing of a current and so makes and breaks a circuit by vibrating backwards and forwards.

10. The *commutator* is used to cut off or reverse the direction of the battery current at will. In Ruhmkorff's coil, it consists of a small wiry cylinder, covered with two brass cheeks, against the sides of which two springs, joined to the ends of the primary coil, press. The battery poles are connected through the ends of the axis of the cylinder to the two cheeks which can be turned so as to place them either way in contact with the two springs.

11. Condenser.—It is interposed in the primary circuit. It consists of alternate layers of tin foil and silk, into which the current flows whenever circuit is *broken.* At each break of the inducing current an extra current is produced in the *same* direction, which continuing prolongs its duration. It is this extra current which produces the spark at the interrupter (at each break). By interposing the condenser in the inducing current, the extra current instead of producing a spark passes into the condenser. When the circuit is open this *extra current* passes into the condenser through the primary coil in the direction *opposite* to the *inducing* current, which instantaneously demagnetises the core of soft iron, the induced current is thus made shorter and more intense. The condenser becomes charged every time the battery circuit is completed, and discharges itself by a reverse current through the primary coil every time the circuit is broken. The condenser is generally placed in the wooden case at the bottom of the instrument. The object of the condenser is (1) to *make* the break of circuit more sudden by preventing the spark of *extra* current from leaping across the interrupter, (2) to store up the electricity of this self-induced extra current in order that when the circuit is again made, the current shall attain its full strength *gradually* instead of suddenly, thereby causing the inductive action in the secondary circuit at *make* to be comparatively *feeble.*



A, Iron Core ;
B, Vibrating Hammer ;
Big dots, sections of the wires in the primary coil ;
Small dots, sections of the wires in the secondary coil ;
D, adjusting screw.

PARTS OF RUHMKORFF'S COIL AND THEIR USES.

1. Commutator (placed in the primary coil) ...	To admit or cut off the current or reverse its direction.
2. Primary Coil ...	To receive the inducing current from the battery.
3. Vibrating Hammer ...	For alternately making and breaking contact in the primary current.
4. Iron Core ...	(1) To render the vibrating hammer self-acting. (2) To increase the inductive action of the primary current by being converted into a magnet.

5 Condenser	(1) To reduce the direct extra sparks at every break, which destroy the hammer. (2) To increase the inductive action of the primary coil by demagnetising the core more completely and magnetising it more suddenly.
6. Secondary Coil	In it the induced current is generated.

12. Effects of Induction coil—Induced currents are produced in the coil at each make and break of the contact. The *direct current is* of *shorter duration* but *higher electro-motive force.* When the *ends* of the secondary coil are *connected*, *currents traveres* it *alternately* in *opposite* directions as the primary circuit is made and broken (water may be decomposed by it). If the ends are disconnected, so that only disruptive discharge can take place, only the *direct* current *passes* (*i.e.*, that produced by breaking the circuit). The inverse current being of low electro-motive force cannot overcome the resistance of the air between the poles. By means of this apparatus very powerful *physiological effects* are produced giving violent shocks. Heat and light may be produced and chemical decomposition and combination may be effected. If the two ends of the secondary coil be brought near one another, light is seen but water is not decomposed, unless the intensity is increased sufficiently. *Luminous effects* of the induction coil (which are very remarkable) vary according as they are produced in air, in vapour or in very rarefied gases. In a vacuum a beautiful trail of light is seen from the one pole to the other, the positive pole shows the greatest brilliancy and its light is of a fine red colour accumulated to the tip, while the light of the negative pole is of a feeble violet colour and extends along all the length of the wire. The colour depends upon the nature of the vapour and of the *pole.* These phenomena are seen in Geissler's tubes (*i.e.*, glass tubes of various shapes, containing rarefied gases and vapours in them).

12. *a.* To *charge a battery or a Leyden Jar* the outer coating is connected with one pole of the coil and the inner coating with the other, by the *two rods of the discharger* (which may be separated at will) and metallic wires. The two rods are then separated, and placed in such a position that the direct current *i.e.*, that *on opening*, which has the greater tension can pass across the air and the jar is charged. If the two coatings be connected respectively with the two poles, which are also connected with the two rods of the discharger, the battery is constantly charged (sometimes in one direction and sometimes in another) and as constantly discharged through the rods; but if the rods are separated, the discharge becomes more violent and detonating but the length of the spark is very much diminished.

13. **Action of magnets on induced currents in rarefied gases.**—A soft iron rod is fitted in the interior of a glass vessel from which air can be exhausted, and is coated with an insulating substance to prevent discharge between it and a metal ring which surrounds it near its lower end. When the poles of a battery are connected, one with the ring and the other with the upper end of the apparatus, a luminous sheaf extends from the summit towards the wire ring and surrounds the soft iron. If now the rod is magnetised by some means, the luminous streaks are condensed into a single luminous arc and begin to revolve round the rod (in the direction stated above). From this it is said that the rotatory motion observed in the Aurora is due to the influence of terrestrial magnetism.

14. **Telephone.**—The first successful attempt to transmit sound electrically was made by Ries. He constructed a hollow box, into one side of which a mouthpiece was inserted while another side was made of a thin membrane. On this membrane was a piece of thin metal foil connected by a wire with one pole of a battery, its other pole being connected with the earth. Just above the foil and almost touching it was a metal point connected by the line wire with one end of an insulated coil surrounding an iron rod, the other end of the coil was put to earth. This rod, which was used as the receiver, was fixed on a sounding board. The sound produced by speaking into the mouthpiece set the membrane in vibration. This alternately opened and closed the current. These *makes* and *breaks* alternately magnetised and demagnetised the rod rapidly and the sound was produced.

15. **Graham Bell's Telephone.**—It consists of an elastic plate of thin sheet iron, placed behind a conical mouth-piece to which the speaker places his mouth or the hearer his ear. Behind the disc is a magnet running the length of the instrument, and round the pole, which nearly touches the disc, is fitted a thin flat coil of fine insulated copper wire the ends of the wire being connected with the binding screws. One such instrument is used to transmit sounds, another to receive them, the two being connected by wires in a simple circuit. The action of the instrument depends upon the fact that when a conducting wire is moved within the field of a magnet, a current is induced in the wire. In this instrument the soft iron disc, which is magnetised by the inductive action of the magnet, is vibrated by the sound

wave, so its relative position with the coil is changed and the currents are produced in alternate directions in the coil. These currents produce a change in the magnetic distribution of the magnet which produces currents again in the same direction as above. These currents being transmitted through the circuit to the distant coil put the other disc in vibration. These vibrations are perceived as sound precisely corresponding to that which is transmitted (*i.e.*, these vibrations being repeated sound is reproduced). The reproduction is perfect as far as articulation is concerned, but it is considerably enfeebled. This instrument has now-a-days been applied to speak to men at a great distance.

THERMO-ELECTRICITY.

16. Seebeck's discovery.—Seebeck discovered that a current may be produced in a closed circuit by heating the junction of two dissimilar metals. Thus if a piece of bismuth and a piece of antimony be soldered together and their free ends be connected with a galvanometer, it is found that if the *junction* be *heated* to a temperature higher than that of the rest of the circuit, a current flows whose *direction across the heated point* is *from bismuth to antimony.* If the junction be *cooled* below the temperature of the rest of the circuit *a current in the opposite direction* is generated. The strength of the current is always proportional to the difference of temperature of the parts up to a certain point. These currents are called *thermo-electric currents. They may* also *be proved* by Seebeck's rectangle consisting of two plates of bismuth and antimony soldered on both ends. In the interior is a magnetic needle placed on a pivot. If one end is heated the magnetic needle is deflected showing the presence of electric current. By experimenting with different metals, it has been found that a metal becomes charged with positive electricity when associated with one, and negative electricity with another.

17. Nobili's thermopile.—He constructed this instrument by joining couples of bismuth and antimony in different rows in such a manner that antimony of the first row is joined to the bismuth of the second. The couples are insulated from one another by varnished papers. Two binding screws are connected one with the first antimony and the other with the last bismuth. These are connected with a galvanometer, in which the current is to be measured. When one face is exposed to heat, a current is generated in each couple in the same direction and the total current is the sum of all the currents.

18. Peltier effect—Peltier also discovered a phenomenon which is the converse of that discovered by Seebeck, namely, that *if a current of electricity be passed through a junction* of dissimilar metals the junction *is either heated or cooled, according to the direction of the current.* This is called the " Peltier effect."

QUESTION.

1. When does an electric current induce current on conductors ? (2) Prove experimentally the laws which govern the production of induced currents. (3). Describe the experiment which proves the inductive influence of the earth on a conductor in motion (4).

3. What is *extra current* ? (7). Is there any relation between it and the induced current ? Describe the construction of the Ruhmkorff's coil, stating fully the functions of the *interrupter, commutator, and condenser* (8, 9, 10).

4. Describe some of the experiments performed by the Induction coil. (12). How can a Leyden jar be charged with this ? (12 *a*). Prove that magnets exert influence on induced currents in rarefied gases. (13).

5. Explain clearly the principle on which Telephones are constructed (14) Describe Graham Bell's telephone. (15).

6. What is meant by 'thermo-electricity' ? Describe the experiment which led to the discovery of this phenomenon. (16).

7. Describe the construction of Nobili's thermopile (17). What is meant by *Peltier effect*" ? (18).

The following table shows the effects of electric currents, their nature and laws :—

EFFECTS.	NATURE.	LAW.	APPLICATION.	REMARKS.
1. Physiological.	Contraction of nerves and muscles by a current passing through them.			
2. Mechanical...	Fractures caused by currents passing through bad conductors.			
3. Physical—				
(*a*) Heating ...	Conductors traversed by currents are heated.	Temperature varies inversely as the thickness of the wire.	Blasting.	The *thinner* the wire, the *hotter* it becomes when traversed by the same current.
(*b*) Luminous ...	Bodies traversed by currents sometimes become luminous.		Swan's Lamp.	
(*c*) Effects on magnets	Deflection of magnetic needles by currents in the neighbourhood.	Ampere's rule—If a person swims along the current with his face towards the needle, he sees the N. pole deflected towards his left hand.	Galvanometer; needle telegraphy.	

(*d*) Effects on magnetic bodies	They are magnetised by currents flowing round them.	The direction of the current at the *south pole* of the magnet thus formed, is *clockwise* to the man turning his face towards the pole ; and *counter clockwise* at the *N. pole.*	Electromagnet. Morse's telegraphy. Electric call-bell.	
(*e*) Effects on other electric currents	Attraction and Repulsion.	Two currents in the same direction attract each other, in opposite directions repel.	Roget's dancing spiral.	
(*f*) On conductors in the neighbourhood	Momentary currents are *induced* in conductors by currents flowing in the neighbourhood.	When the current *begins* to flow or *increases* in strength an *inverse* current is induced. When the current *ceases* to flow or *decreases* in strength a *direct* current is induced.	Ruhmkorff's coil.	Steady currents cannot induce a current in the neighbouring circuit.
4. Chemical	Combination and decomposition of bodies.		Electrolysis. Electro-typing. Electro-plating.	

CALCUTTA UNIVERSITY F. A. PAPERS.

In the following P. stands for page, A. for article.

1885.

ELEMENTARY PHYSICS.

1. How do you conceive the constitution of matter? Account for the various states in which water is found in nature. (P. 7, A. 8,) (P. 4. A. 7.)

2. What is meant by inertia, and give two cases of each kind of inertia? (P. 6. A. 8.)

3. Explain fully with diagrams the construction, effects, and principles of Bramah's hydraulic press. (P. 8. A. 12.)

4. Describe and explain the conditions of the various movements of the Cartesian diver. P. 16. A. 29.)

5. Give three different methods for the determination of the specific gravity of solid bodies. (P. 17. A. 31.)

6. Describe the way in which the ordinary mercurial thermometer is made and graduated. Pp. 57, 58, 59, Aa 3, 4, 5 and 6.)

7. What is meant by evaporation, ebullition, latent heat, specific heat, and spheroidal state? (Pp. 74, 76, 70, Aa 8, 9 and 4.)

8. Give the ordinary theory of the formation of dew, and say how the dew-point is determined.—*Omitted since*

9. Describe the various parts and explain the action of Watt's double-acting engine. (P. 94 and 95.)

10. In how many different ways is heat propagated? Give one example of each. (P. 81, A. 1.)

LIGHT AND ELECTRICITY.

1. Define the following terms: "Opaque", "Translucent", "Luminous", "Shadow", "Penumbra", "Intensity", "Ray", and "Pencil". Describe a Photometer and state its uses. (P. 99, Aa. 1, 2; P, 103, A. 8; P. 105; P. 107, A. 12.)

2. A pencil of light meets the surface of a transparent medium. What change does it undergo? Name the different kinds of mirrors and lenses, and define the terms "Principal and Secondary axes and foci" and "Virtual and Real images" as applied to mirrors and lenses. (P. 101 A. 5; P. 113, A. 2; P. 115, A. 7, 8; P. 129, A. 19; P. 131, A. 22; P. 130, A. 20.)

3. Show by sketches the arrangement of lenses in an astronomical telescope, a terrestrial telescope, and microscope, and give reasons for each. (P. 138, A. 3; P. 139, A 7.)

4. What is a magnet and a magnetic substance? How are they distinguished? Define the poles of a magnet, and describe their reciprocal action. (P. 146, A. 5, P. 145, A. 3; P. 144, A. 2.)

5. What are "conductors", "non-conductors", and "insulators", in electricity? Describe experiments showing that electricity accumulates on the surface of bodies, and discuss the influence of points on electrified conductors. (P. 153, A. 7; P. 155, A. 10, 11; P. 156, A. 13.)

6. What is electrical induction? Describe the action of the "Plate Electrical Machine" and of the "Leyden Jar." (P.157, A. 14; P. 160, A. 2; P. 167, A. 21.)

7. Describe Wollaston's and Daniell's voltaic cells. What is the defect of the former and its cause, and how is it removed in the latter? (P. 178, A. 8; P. 179, A. 9, P. 177, A. 7.)

8. State, fully, the action of a current on magnet, and show how this is utilized in the construction of a galvanometer. (P. 187, A. 2; P. 188, A. 3.)

9. Describe a solenoid and an electro-magnet, and state the theory of Magnetism based upon their behaviour towards magnets. (P. 189, A. 5; P. 191, A 7; P. 192, A. 8.)

1886.

GENERAL IDEAS AND HEAT.

1. State and give sketches illustrating, what is meant by the parallelogram of forces and the composition and resolution of forces. (P. 41, last para, P. 42, A. 5.)

A river is flowing at the rate of 30 feet a minute; show by a sketch the direction a boat, capable of being rowed at the rate of 120 feet per minute, must take so as to reach a point directly opposite that from which it started.

AB is the direction of flow, AC, the direction in which the boat must move to reach AD.

The direction *of the resultant is perpendicular to the direction oj* flow.

2. Describe and give sketches of the different kinds of levers, and give some applications of each.

Describe the common balance and the steel yard, and state the conditions the former has to satisfy.—*Omitted since.* (P. 46, A. 9.)

3. State the characteristic properties of liquids, and mention what you know regarding the pressures of fluids (1) including, (2) neglecting, their own weights. Sketch and explain the action of "Barker's Mill." (P. 7, A. 10; Pp 8, 9, 10, Aa. 11, 12, 13, 14, 15, 16.)

4. State the laws regarding the equilibrium of liquids, and note some useful applications of the same. (Pp. 11, 12. Aa. 18, 19, 20, 21.)

Given two vertical tubes, A and B, communicating at the bottom, and two liquids, C and D, whose densities are 1·25 and 0·8 respectively. C is now poured into A, then D into B, giving a depth of

1 foot of D above their common surface. What will be the corresponding height of C in A?

From P. 12, A. 20 we have $\frac{h'}{h}=\frac{d}{d'}$. Here $h=1$ ft ; $d=.8$

$$d'=1.25 \because h'=\frac{h.d}{d'}=\frac{1\times .8}{1.25}=.64.$$

5. Name the different kinds of pumps in use, and give sketches showing their action. To which is an air-chamber applied, and what is its action and use? (Pp. 33-34, Aa 50-51.)

6. State the general effects of heat upon bodies, and discuss the relation of heat to the different states of matter. (P. 53, A. 3.)

7. Define the co-efficient of expansion of bodies. Distinguish between absolute and apparent expansion, and state to which class of bodies these terms apply. Describe the object, action, and construction of the compensation pendulum. (P. 54, A. 4 ; P. 64, A. 1 ; P. 62, A. 13.)

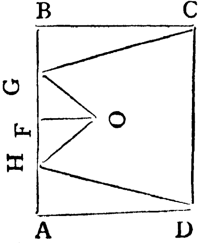
8. Distinguish between saturated and non-saturated vapours, and give the laws regarding the tension of the former. Define evaporation and ebullition, and state the effect of atmospheric pressure on both. (P. 74, A. 76 ; P. 73, A. 6 ; P. 74, A. 8 ; P. 76, A. 9.)

9. Explain the production of cold by evaporation, and mention some useful applications of this property. Explain the cooling effect of the Punkah. (P. 79, A. 13.)

LIGHT AND ELECTRICITY.

1. Five equal candles burn in a cluster at one end of a rod, and two similar candles at the other end. How and on what principles would you place a sheet of paper on the rod so as to have equal illumination on both sides? (P. 109, A. 13.)

2. A square plane mirror is hung exactly, in the centre of one of the walls of a cubic room ; an observer with his eye exactly in the centre of the room is just able to see the whole of the opposite wall reflected in the mirror. What is the size of the mirror, and by what construction do you find it?



ABCD represents the section of the cubic room, O, the position of the observer in the middle ($OF=\frac{1}{2}BC$) HG, the mirror, CG and DH incident rays which after reflection from G and H respectively enter O ; triangles BGC and OGF are similar $\therefore \frac{BG}{GF}=\frac{BC}{OF}=2 \therefore BG=2GF$ Similarly $AH=2FH \therefore 2(GF+FH)=2GH=BG+AH \therefore 3GH=BG+AH+GH=AB$ *i.e.* the length of the wall is three times that of the mirror.

3. Show by a diagram the manner in which a stick appears bent when plunged obliquely in water. Explain the appearance. (P. 125, A. 6.)

4. What do you understand by principal focus, secondary axis, conjugate foci, real and virtual images in spherical mirror? (P. 116, A. 8; P. 113, A. 2.)

5. What colours would appear black in a room in which the sun's light is admitted only through a red glass? *Ans: all other primary colours except red.*

6. What are the conditions required for the formation of a rainbow?—*Omitted since.*

7. Describe the compound microscope, and explain its action. (P. 139, A. 7)

8. State the general laws of distribution of static electricity on conductors. Describe the distribution on a hollow tin tube open at both ends. How is it modified by the approach of your hand at one end? (P. 155, Aa 10-11)

9. Explain how a condenser such as a Leyden jar is charged, and in how many ways can it be discharged? (P. 167, A. 21)

10. What is a lightning conductor; in what way does it act; and how would you extemporise one for a detached building?—*Omitted since.*

11. Describe fully any form of constant battery such as Grove's, Daniell's or Bunsen's. (Pp. 179, 80 Aa. 1-3)

12. Describe exactly how you would obtain *(a)* a current of frictional electricity, *(b)* one of voltaic electricity, *(c)* one of thermo-electricity, *(d)* one of induced electricity.

Hints—(a) By connecting the prime conductor of the electrical machine with the earth by a metal wire *(b)* By joining the plates immersed in the cell by a metal wire *(c)* By heating one of the points of junction of a thermo-electric-element *(d)* By making and breaking the circuit of a voltaic cell near a conductor, currents may be induced in the latter.

13. Explain the action of an ordinary glavanometer. (P. 188, A.3.

1887.

GENERAL IDEAS AND HEAT.

1. Define the term acceleration. Describe any method with which you are acquainted (*a*) of establishing experimentally the uniformity, (*b*) of determining experimentally the intensity of the acceleration produced by gravity in a body moving freely under its action. (P. 39, A. 2)

2 Define the centre of gravity of a body. Explain how the centre of gravity of a body may be determined by experiment. Show how to find by geometry the position of the centre of gravity of a triangular plate. (P. 44, A. 7)

3. What is the characteristic distinction between solids and liquids in regard to the transmission of pressure? Show that pressure exerted anywhere upon a mass of liquid is transmitted equally in all directions and acts with the same force on all equal portions of the containing surface. (P. 8, A. 11)

The Diameter of the larger cylinder of a Bramah's press is 12 inches, and of the smaller ¼ inch. What weight can be raised by the larger cylinder when a pressure of 20 pounds is applied to the smaller?

3. From P. 8. A. 12 we get

$$\frac{D^2}{d^2}=\frac{W}{w}$$

where D and *d* are the diameters of the larger and smaller cylinders respectively;
W = wt raised by the larger cylinder
w = wt put upon the smaller one

$$\frac{(12)^2}{(\frac{1}{4})^2}=\frac{W}{20}$$

∴ W = 20 × 144 × 16 = 46080 lbs.

4. Describe two methods of determining experimentally, taking water as the standard, the specific gravities of ordinary homogeneous substances, solid and liquid. (P. 17. A. 31; P. 19, A. 32)

5. Sketch and describe the construction and action of the air-pump. (P. 30, Aa. 46-47)

The volume of the receiver of an air pump is 200 cubic inches, while the volume of the barrel is 20 cubic inches. What proportion of the original air will be left in the receiver after the third stroke?

6. Explain clearly each of the three processes, Conduction, Convection and Radiation, by which heat is transferred from one place to another. (P. 81, A. 1)

A piece of china-ware with a dark pattern on a light ground is strongly heated in a bright fire. When examined in a dark room it now appears to have a light pattern on a dark ground. Explain this. (*Omitted.*)

7. What is meant by the latent heat of fusion, and the latent heat of vaporisation? If the former be represented by 79·25, and the latter by 536 units of heat, compare the heat necessary to raise a pound of water from 0°C. to 100° with that required to convert a pound of ice at 0°C. into steam at 100°. (P. 70, A. 4; P. 78, A. 12)

8. Describe the method by which Dalton first measured the pressure of aqueous vapour for temperatures between 0° and 100° (P. 78. A. 11)

Water is boiled in two tubes, the depth of water in one tube being five times as great as in the other. It is observed that bubbles of steam rise from the bottom of one tube at a temperature they do not rise from that of the other. Explain this.

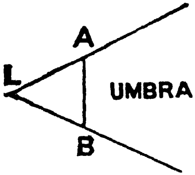
Hints—the boiling point of a liquid increases with the pressure.

9. Define the specific heat of a substance, and describe how

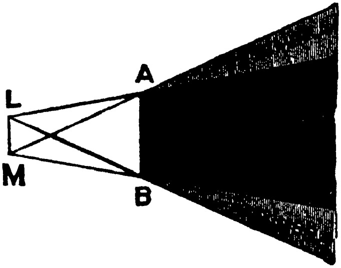
specific heats are determined by the method of mixtures.—*Omitted since.*

LIGHT AND ELECTRICITY.

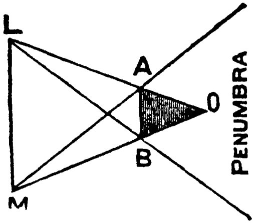
1. Show by a diagram that three cases may occur in the production of shadows :—(1) sharply defined shadow, (2) shadow fringed with penumbra, and (3) penumbra without shadow.



L, the source of light ;
AB, the opaque body.



LM, the luminous body,
AB, the opaque body.



LM, the luminous body is larger than the object.

2. Give the laws regulating the intensity of light, and say at what distance of a screen two lights of intensity three and nine respectively must be placed to give equal illumination. (P. 105 ; P. 109 Q. 2)

3. Define :—Critical angle, prism, total reflection, colour andoptical centre. (P. 125, A. 8 ; P. 128, A. 16 ; P. 130)

4. Describe a spectroscope, and show how it may be used to identify an elementary substance.—Pp. 142-43 ; Aa. 5-67.

5. How would you show experimentally that both electricities are always generated together and in equal quantities? (P. 152, A. 51)

6. Describe fully the process by which a copper facsimile of a model is obtained by electricity (P, 114, A. 14)

7. How does thermo-electricity enable us to measure the temperature of an inaccessible point ?

Hints—If two wires made of platinum and silver are joined at their extremities and a galvanometer is inserted in the arrangement, and then one point of junction is kept in the place whose temperature is to be determined and the other immersed in a bath, *so long as the two* *points* of junction are at *different temperatures*, the *galvanometer* will *be deflected* ; altering the temperature of the bath, the galvanometer may be brought to zero. This is the case, generally, when the two points of junction are at the temperature ; here then the temperature of the bath will be the same as that of the inaccessible point.

1888.

GENERAL IDEAS AND HEAT.

1. Give some explanation of the difference between solids liquids, and gases, and state clearly what these differences are (P. 4, A. 7)

2. Define velocity, acceleration, and force. Explain what is meant by inertia, giving three instances of its effects. (P. 2; P. 39, Aa. 1-2)

3. What is meant by the pressure of a fluid? How does it vary with the depth? If a cubic foot of water weighs 62.5 ℔, what is the pressure per square inch at the bottom of a tank containing water 50 feet deep?

The pressure on a sq inch at the bottom of the tank is the weight of a column of water whose base is one sq. in and height 50 feet.

$$\text{Volume of the column} = \frac{1}{144} \times 50 = \frac{25}{72} \text{cub. feet}$$

$$\therefore \text{Pressure} = \frac{25}{72} \times 62.5 = 21.7 \text{ ℔ nearly}$$

4. Why is a pendulum used for measuring time? In order that a pendulum may vibrate always at the same rate, what conditions must be fulfilled? A seconds pendulum is about 39 inches long, what is the length of one which beats only once in three seconds (P. 49.)

5. State the laws of falling bodies, and explain how they can be demonstrated by means of an inclined plane. If a body falls 16 feet in the first second, how long will it take to fall 200 feet? (P. 47, A. 10)

6. How can you tell which of two bodies is the warmer when the difference is too small to be detected by hand? Some pieces of ice are added to a small quantity of water, and the mixture is briskly stirred, after which the temperatures are quickly observed. whether is the ice or the water the warmer?

Hints—The ice will remain at the melting temperature until the whole of it is melted. But if the quantity of water is large compared with the mass of ice, water will always be at a higher temperature, till all the ice is melted ; but if the quantity is too small to melt the whole of ice, its temperature will be the same as that of melting ice.

7. How do you account for the fact that much heat is required to convert a kettle full of boiling water into steam, while to the hand the water feels hotter than the steam?

Hints—Water is a better conductor than steam

8. Air contains more or less water vapour. How would you demonstrate this and find the hygrometric state of air? Explain how this vapour is converted into cloud and rain.—*Omitted since.*

9. Describe some experiments to show that water expands when heated, and that air expands much more. (P. 55, A. 8)

10. What is combustion? Which of the following substances are combustible, and if equal weights are taken, which of them will, on burning, give most heat?—Charcoal, chalk, wood, glass, diamond, sulphur, slate, petroleum.—*Omitted* since.

MAGNETISM, ELECTRICITY AND LIGHT.

1. What distinction is there between magnets and magnetic substances? (P. 146, A. 5)

A dozen steel sewing needles are hung in a bunch by threads through their eyes. How will they behave when hung over the pole of a strong magnet?

The pointed ends shall repel one another being identically magnetised by induction.

2. Explain the action of electrophorus. (P. 161, A. 5)

3. By what experiments could you prove the identity of frictional and voltaic electricity? (P. 182, A. 10)

4. What are the causes which produce the enfeeblement of current in voltaic batteries? Explain the construction and action of three of the well known types of constant batteries. (P. 177, A. 70; P. 179, A. 9)

5 Explain the principle and construction of Ruhmkorff's coil (P. 198, A. 8)

6. How would you compare the illuminating powers of two sources of light by Bunsen's photometer? Explain the principle involved. (P. 107, A. 12)

7. Account for the fact that a coin placed in water appears higher than it really is. (P. 125, A. 6)

8. Draw diagrams showing how a double convex lens may be used as a magnifying glass or to form a real image of a distant object. (P. 132, A'a 23-24)

9. Describe a simple form of spectroscope, and trace the passage of a beam of light through the instrument. (P. 142, A. 6)

1889.

GENERAL IDEAS.

1. State the laws of falling bodies. (P. 47, A. 10)

2. When is a body in equilibrium under the action of gravity? Give one example of each of three kinds or states of equilibrium. (P. 44 Ar 7

3. State clearly the principle of Archimedes, and show how the safety of a ship, loaded at a sea-port, might be endangered, on her going up a river, by the oversight of the above named principle. (P. 14. A. 25)

River-water is lighter than Sea-water, therefore the ship sinks to a greater depth, when it enters into a river

4. What is meant by the specific gravity of a body, and how would you find out the specific gravity of (*a*) a lump of lead, (*b*) sulphuric acid, (*c*) and of a piece of wood ?

5. A lever, whose weight is neglected, has its fulcrum at one of its extremities, and a weight of 15 ℔s. at the other, acting downwards ; what will be the pressure in ℔s upon a body placed in succession at one-third and one-fourth from the fulcrum ?—*Omitted since.*

HEAT.

1. Explain briefly the construction of three different thermometers, the principle of one depending on the expansion of a liquid, that of the second on the difference in the expansion of strips of different metals, and that of the third on electrical currents produced by heat. (P. 57, A. 3 ; P. 63, A. 2 ; P. 203, A. 17)

The second is the spiral thermometer.

2. Describe a gridiron pendulum made of copper and iron bars. What must be the relative lengths of the two metals. ? (P. 62, A 13)

Coefficient of linear expansion of copper..................·000017
" " " iron..................000011

3. Describe any experiment by which it can be proved that the density of water is greatest at 4°C. State some of the effects due to this property of water in the economy of nature. (P. 65, Aa. 4-5)

4. Explain how the height of a mountain may be determined by observation of the boiling-point of water. (P. 77, A. 10)

5. Define specific heat. Describe two different methods by which the specific heat of a solid may be determined.—*Omitted since.*

ELECTRICITY AND LIGHT

1. (*a*) A rod, held in the hand, is rubbed with dry flannel. What property of the material of which the rod is composed determines whether it becomes electrified or not ?

Nonconductor of electricity.

If it does become electrified, how would you ascertain the kind of electrification ? (P. 151, A. 4)

(*b*) The best way of completely discharging the rod is to pass it through or over the flame of a spiritual lamp. Explain this.

Second law of distribution of electricity.

2. You hold a Leyden jar by the knob, and present the external coating to the prime conductor of an electrical machine in action.

After some time you place it on the ground. Describe and explain what happens. (P. 167, A. 21)

3. Explain clearly how the prime conductor in Ramsden's machine becomes charged with electricity. (P. 167, 1. 21)

4. The ends of two copper wires leading to a concealed Bunsen's battery are free. How could you find out, by means of a solution of copper sulphate, which wire is connected with the carbon, and which with the zinc terminal of the battery?

Copper resulting from the decomposition of copper sulphate will be deposited on the negative electrode.

5. (*a*) You are given some covered copper wire, a rod of soft iron. and a Bunsen's cell. Describe in detail how you would proceed to make a given end of the rod the north pole of a magnet. Draw a diagram. (P. 189, A. 5)

(*b*) Is it essential for the copper wire to be covered?

Yes; for the wire should be insulated.

6. A vertical coil of covered copper wire is connected with a delicate galvanometer. Describe what happens when the south pole of a bar magnet is suddenly introduced within the coil, and after a short time as suddenly withdrawn. How does the experiment illustrate Ampere's theory of magnetism? (P. 197 A. 4)

7. Describe an experiment to prove that the effect of the earth on a magnet is merely directive, and give some explanation of the fact. (P. 147, A. 9)

A magnetic needle balanced upon a cork floating on water is not drawn in any direction but is directed so as to point north and south.

8. A luminous point is placed on the principal axis of a concave spherical mirror. Trace the changes in the behaviour of a reflected ray, as the luminous point is moved up to the mirror from a point at any distance beyond the centre of curvature. (P. 117, A, 11; P. 120, A. 14)

9. You are given a candle, a glass water-bottle, a sheet of thick plate-glass, and a screen. Explain, with the help of a diagram, how you could make the candle seem, to a spectator, to be burning inside the bottle.

Place the bottle behind, and the candle in front of, the glass-plate so that the image of the bottle by refraction and the image of the candle by reflection may be formed at the same position behind the glass-plate. The screen is to intercept the direct rays from the candle.

10. (*a*) A vessel contains water upon which floats a layer of turpentine. Make a sketch, showing clearly the course of rays diverging from a luminous point in the water; the index of refraction of water being given as $\frac{4}{3}$, and that of trupentine as $\frac{3}{2}$.

(*b*) A ray of light, which enters into a right-angled isosceles prism at right-angles to one of the faces adjacent to the right angle passes out through the other face adjacent to the right angle without having been refracted at all. Account for this.

(*c*) *This occurs when the prism is made of glass, for then the ray meets the base of the prism at an angle greater than the critical angle (for glass); consequently light is* **totally reflected**

11. (*a*) Describe the common terrestrial telecope, explaining the use of the various parts. Illustrate your answer by means of a diagram.—*Omitted since.*

(*b*) Why is it necessary to alter the position of the eyepiece for different observers?

The distance of distinct vision is not the same for all observers.

12. A mixture of methylated spirits and common salt burns with a strong yellow light. Describe and explain the appearance of a number of variously coloured flowers examined by this light in a room otherwise dark.—*Omitted since.*

1890.

GENERAL IDEAS.

1. Define the following terms:—Mass, force, energy, equilibrium, cohesion, density. (P. 2, A. 2; P. 39, A. 1)

2. State the principle, and describe the essential parts of Atwood's machine. How would you use it to prove that "the "velocity generated by a constant force is proportional to the time during which the force has acted?"—*Omitted since.*

What conditions must a balance fulfil in order that its weighings must be accurate? How may the true weight of a body be ascertained by means of an inaccurate balance?—*Omitted since.*

4. A cork floats in a vessel of water placed under the receiver of an airpump. Will the cork rise or sink on exhausting the receiver? Give reasons for the answer you make. (P. 38, A. 1)

5. Describe the Syphon, and explain its action. (P. 34, A. 52)

6. Enunciate Boyle's law, and describe any simple experiment by which it may be verified. (P. 27, A. 44)

A bubble of air is formed 100 feet below the surface of water. State approximately its volume on reaching the surface, as compared with its original volume.

Hints—Let the height of the water-barometer be 33 *ft.* The *bubble was* originally *under the pressure* exerted by a column of 100 *ft.* of water + 33 *ft.* of water due to the *atmospheric pressure.* When it comes to the surface the *pressure* on it is *one atmosphere i.e.* that exerted by a column of 33 ft of water. If V be the original and V1 the final volume of the bubble, then from Boyle's law we have $V \times 133 = V1 \times 33, \therefore \frac{V1}{V} = \frac{133}{33} = 4$ nearly.

HEAT.

1. What relation exists between the reflecting, absorbing, and emissive powers of a substance? Give examples. (P. 89, A. 5)

What is meant by diathermaneity? Show that a transparent substance is not necessarily diathermanous and vice versa. (*Omitted*)

2. Define what is meant by the terms "latent heat of fusion' and "latent heat of evaporation." (P. 70, A. 4,)

What are the meanings of the terms "saturated space" and maximum tension with reference to vapours? (P. 79, A. 11.)

What causes accelerate evaporation? (P. 74, A. 7)

State the laws of ebullition, and enumerate the causes which influence the boiling-point of a liquid. (P. 75, A. 8) (P. 76, A. 9.)

3. Give a general definition of the term "thermal unit." (P. 80, A. 1.)

Describe the method of mixtures in the determination of specific heats.—*Omitted since.*

How much water at 100° C. can be evaporated, and how much ice at 0° C can be melted by the heat given out by 10 kilograms of copper, when cooling down from 1,000° C to 100° C in the first case, and from 1,000° C to 0°c in the second place?

4. What is the province of hygrometry? What is meant by "dew-point"?

Draw sketches of Daniell's hygrometer and of the psychrometer at the same time giving brief description of these instruments.

Describe how the hygrometric state of the atmosphere is ascertained by the aid of the former instrument.—*Omitted since.*

5. Enumerate the different sources of heat and describe some lecture experiments which illustrate the production of heat by the friction and compression. (P. 69, A. 1, 2, 3)

Supposing 0·1 gram of hydrogen to be burnt in a calorimeter containing, 1 kilogram of water originally at 20° C; what would be the final temperature of the water in Centigrade, Reaumur, and Fahrenheit degrees, if all the heat given out by the burning hydrogen were imparted to the water? (The combustion of one pound of hydrogen yields 34,000 thermal unit, also 1 kilogram = 1,000 grams.) (*Omitted since.*)

LIGHT.

1. Explain by a diagram the method employed by Roemer to calculate the velocity of light. (P. 109, A. 9.)

2. Describe any photometer you are acquainted with, and explain how the relative intensities of two sources of light may be determined by its use. (P. 107, A. 12.)

3. Show by diagrams the formation of real and virtual images by concave mirrors. (P. 118, A. 13)

4. Write what you know about the solar spectrum, and the

means of obtaining a pure spectrum. What are the dark lines seen in such a spectrum,and what their is meaning in relation to spectrum analysis? (Pp. 141—2, Aa. 3—5.)

5. Give an idea of the human eye considered as an optical instrument, and explain how its defects are remedied by the use of spectacles.—*Omitted since.*

ELECTRICITY AND MAGNETISM.

1. By what experiments could you prove that there are two kinds of electricity? (P. 151, A. 4.)

2. Explain the principle and construction of a gold-leaf electroscope. (P. 163, A. 8.)

The knob of an electroscope has a pointed needle attached to it. A glass rod rubbed with silk is brought near the needle and then removed. Explain the indication of the instrument.

3. Explain the principle of electro-plating. Describe an arrangement by which a brass vessel may be plated with silver. (P. 184, A. 14.)

4. Enumerate the different methods you know by which you could detect the existence of an electrical current in a given wire. Which of these methods would enable you to find the direction of the current as well? (P. Table.)

5. Explain the principle and action of a telephone. (P. 201, A. 15.)

6. What experiments would you perform to find out whether a given bar of iron is magnetised or not? (P. 145. A. 3.)

You are provided with a coil of wire and a delicate galvanometer. What experiment could you further devise to confirm the result previously obtained? (P. 189. A. 5)

1891.

1. What is a balance? Describe briefly the parts of an ordinary balance. How would you ascertain whether a balance is accurate or not? (P. 46, A. 9)

2. What is a pendulum? State the chief laws of the motion of pendulums. A pendulum clock is taken from Calcutta of Darjeeling. What change might be expected in its rate of going? State the cause or causes to which the change would be due. (Pp 49, 50)

3. Gold is said to be 19.36 times heavier than water. What is meant by this statement? Describe any way of finding out exactly how much heavier a metal is than water. (P. 17, A 31)

4. What is a siphon? (P. 34, A. 52)

What would be the effect, 1st, of making a hole in the longer leg below the level of the fluid in which it is placed, and, 2nd, of making one in the shorter leg? (P, 56, A, 2)

5. Describe briefly an experiment showing that solid bodies expand in all directions when heated. (P. 55, . A. 6.)

A long glass tube with a ball is partially filled with a coloured fluid. It is suddenly dipped into hot water. The column of liquid in the tube first appears to sink, and then rises rapidly. Explain this action. (P. 64, A. 1.)

6. It is stated that the latent heat of the fusion of ice (or the latent heat of water)is 80. Explain fully this statement and describe an experiment verifying it. (P. 70. A. 4.)

7. What is meant by the reflection of light? Under what circumstances does it occur? Give laws of reflection. (P. 110, A 1.)

8. State and describe briefly the various parts of an astronomical telescope. Explain the use of each essential part of the instrument. What is meant by focussing a telescope? (P. 138, A. 3, 4.)

9. It is stated that the Earth is a magnetic body. Give reasons in support of the statement. (P. 147, A. 9)

10. Describe the gold-leaf electroscope, and explain its action. How would you ascertain by its use the kind of electricity with which a body was charged? (P. 163, A. 8)

11. What is induction by electrical currents?

Describe briefly and explain the use of the different parts of a Ruhmkorff's Induction coil. (P. 196, Aa 1-2 ; Pp. 198-99)

11. What is a closed voltaic circuit? How could it be proved experimentally that in a closed voltaic circuit the strength of the current is everywhere the same? (*By placing a galvanometer at different points of circuit the deflection is found to be the same.*) Explain briefly why at telegraph offices one pole of the battery in use is usually connected with a large plate buried in the ground. (P. 194, A. 12)

ALTERNATIVE PAPER IN PHYSICS.

1. Distinguish between the mass and weight of a body.

It is stated that the weight of a body increases from the equator to the poles. Explain this statement and give reasons. (P. 2, A. 2. P. 43, A. 6.)

2. State the laws of falling bodies. (P. 47, A. 10)

3. Describe an experiment by means of which you can prove that the air at the sea-level presses with a force about 14·7 lbs. per square inch upon everybody with which it is in contact. (P. 26, A. 40.

4. What is Boyle's law? Describe experiments verifying it. (P) 27, A. 44).

5. Describe briefly the construction and graduation of mercurial thermometers.

A fahrenheit thermometer reads 96° under certain conditions. What should a Centigrade thermometer read under same conditions? (Pp. 57, 58, 59, Aa 3, 4, 6 ; P. 60, A. 7,)

6. What is evaporation? State in what respects it differs from boiling or ebullition. (P. 74, A. 8.)

Why does water freely exposed in a shallow vessel in Calcutta evaporate much more slowly in the rains than in the cold weather? (P. 76, A. 9.)

7. Describe an experiment by which it is proved that ordinary white light is a mixture of lights of various colours, (P. 141, A. 3.)

8. What is a lens? Define the principal focus and focal length of a lens. (P. 129, A. 9; P, 131, A. 22)

If you wished to obtain a largely magnified image of a small object, state what kind of a lens you would use and how you would place it with respect to the object. Give reasons so far as you can (P. 132, A. 23)

9. If a magnetic needle be placed upon a cork, and the whole be placed very gently in water, what would happen? What inferences can be drawn from the experiment? (P. 147, A. 9.)

10. Describe the Electrophorus. (P. 161, A 5. 6.)

How would you obtain a series of sparks from the cover?

11. Describe fully the parts and working of a Daniell's cell.

State clearly the uses of each of the two fluids employed. (P. 179, A. 9.)

1892.

PHYSICS.

1. Enunciate the principle of the parallelogram of forces and illustrate it by examples, taken from common life. Two forces of seven and ten pounds' weight respectively, and having the same point of application, act at right angles to each other; find the magnitude of their resultant. (P. 42. A. 5)

2. Prove Archimedes' principle in the case of a cube immersed in a liquid and having four of its edges vertical. How can the truth of the principle be verified by a simple experiment? (P. 14, A. 25)

3. State Boyle's law, and describe how it can be shown to be true for pressures greater than an atmospheric pressure. (P. 57, A. 44)

4. How are the two fixed points of a mercurial thermometer determined? If the temperature of a room is 95° Fahrenheit, what will be indicated by a centigrade thermometer placed in that room? (P. 58, A. 4; P. 60, A. 7.)

5. What is meant by the following statement?

(*a*) The heat of liquifaction of ice is 80·025. (P. 70, A. 4.)

(*b*) The heat of evaporation of alcohol at 78°C. is 208. (Pp. 78 79; A. 12.)

(*c*) The specific heat of lead is 0·0314. (P. 80, A. 3)

(*d*) The maximum pressure of aqueous vapour at 100° C. is 760 mm. of mercury.

6. State the laws of reflection and refraction of light. (P. 110, A. 3, P. 124, A. 3.)

7. What kinds of lenses may be distinguished? Define the

following terms with reference to lenses—principal axis, secondary axis, optical centre, principal focus. (P. 129, 130, 130 A. 19, 20, 21.)

8. How is a Leyden Jar constructed? Why should the outer coating be connected with the ground when the inner is being charged by means of an electrical machine? (P. 167, A. 21.)

9. Describe any two-fluid galvanic element, and explain its action. P. 179, A. 9)

10. How would you show that a solenoid behaves like a magnet, and vice versa? (P. 5, 191, 192.)

1893.

1. Enumerate and define the different states of equilibrium, and give examples. (P. 44, A 7)

2. State the laws of falling bodies, and show how the second law can be demonstrated by experiments with the inclined plain. (P. 47. A. 10)

3. How would you determine the specific gravity of a liquid by the aid of the hydrostatic balance? (P. 19. A. 23.)

4. By what methods would you prove that white light is a mixture of variously coloured rays? (P 141, A. 3.)

5. How would you ascertain the hygrometric state of the atmosphere by means of Daniell's hygrometer? (*Omitted*)

6. "The quantity of electricity produced in induction is equal to that of the inducing body." How would you prove this statement by experiment? (P. 158, A. 15).

7. What are the advantages and disadvantages of Daniell's, Bunsen's and Leclanche's elements? (P. 181, A. 4)

8. Explain the action of the telephone. (P. 202, A. 15.)

1894.

1. What do you understand by acceleration of velocity?

What produces it in a given mass? If a certain acceleration of velocity be represented by 100 when a foot and a second are units, by what number is the same acceleration of velocity represented when one foot and two seconds are units? (P. 46 ; A2.)

2. What is a vapour? Give examples. What is the tension of a vapour? (P. 92 ; A1) Have you seen any of its effects? (P. 72 ; Aa 1 and 4)

3. How is a spectrum of solar light produced and thrown on a screen? (P. 140 ; A1)

4. By what experiments and considerations connected therewith would you attempt to justify the use of such expressions as positive electricity, quantity of electricity? (P. 152 ; A. 5.)

5. Define the electrical resistance of a wire and then state Ohm's Law. (P. 185 ; A 15.)

6. Describe the parts of a Daniell's cell. What is the use of the porous pot? (P. 119, A 9.)

7. What is Archimedes' famous principle ? How is it experimentally verified ? (P. 14 A 25) How is it that a ship made of iron often floats in water. (P. 16 A 28.)

8. Describe how you would make experiments with an electrophorus. (P. 161, A 5.)

Instead of any of the above you may substitute the following :—

Define Momentum. If a certain momentum be represented by 1000 when a gramme, a foot and a second are the units of mass, length and time, by what number must the same momentum be represented when two grammes, three seconds, and four feet are the units ?

1895.

1. State the laws of falling bodies, and illustrate them, as far as possible. by numerical examples. (P. 47, A 10.)

2. What conditions must be satisfied in order that a liquid may be at rest in a wide vessel ? (P. 11, A 18.)

3. Describe an experiment by which you could show that solids differ from each other in their conducting powers. (P 85, A 3.)

4. How is it possible to determine the atmospheric pressure by means of a thermometer, and the temperature of boiling water by the aid of a barometer ? (P. 77, A 10.)

5. Answer one of the following two questions :—

(*a*) How did Faraday prove experimentally that the quantity of electricity produced in induction is equal to that of the inducing body ? P. 158, A 15.)

(*b*) How would you proceed to show that statical electricity resides on the surface of conducting bodies ? (P. 155, A 11.)

6. Distinguish between arc lamps and incandescent lamps, and draw a sketch of an incandescent lamp.

7. Explain the action of any one of the following—the microphone, the telephone, Leclanche's cell, Ruhmkorff's coil. (P. 202, A. 14 ; P. 181, A. 4 ; P. 198, A. 8.)

8. What is meant by a prism in optics ? Trace the path of a ray of light through a prism ; (P. 128, A. 17) and define or explain the terms—angle of incidence, total reflection, refractive index, dispersion, conjugate focus. (P, 110, A. 2 ; P. 126, A. 8 ; P. 124, A. 5 ; P. 140, A. 1 ; P. 116, A. 8.)